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Faculatea de Automatica, Calculatoare si Electronica

Scoala doctorala ”Constantin Belea”

Domeniul : Ingineria sistemelor

TEZA DE DOCTORAT

(Rezumat)

Algoritmi de conducere pentru modele de tip pendul-invers cu componente elastice

Conducator de doctorat,

Prof. univ. dr. ing. Mircea IVĂNESCU

Student,

Van Dong Hai NGUYEN

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In prezenta teza de doctorat, autorul trateaza algoritmi de control pentru roboti cu componente elastice. Teza este focalizata asupra a doua modele majore: modelul pendului inversat si robotul biped cu componente elastic Sunt determinate modelele dinamice si sunt propuse solutii de conducere.

O prima abordare se refera la modelul pendului invesat. Pe baza ecuatiilor dinamice obtinute si utilizand date experimentale de laborator, sunt studiate theoretic si verificate prin simulare cateva solutii de conducere. Sunt abordate astfel cateva tehnici de proiectare a unor controlere te tip conventional, PD sau LQR, nonlineare sau de tip intelligent-fuzzy. Pentru controlerele neliniare propuse se dezvolta tehnologii de proiectare „Sliding mode control" ierarhizate pentru care modelele matematice se prezinta ca sisteme in cascada sub-actionate.

Pe baza modelului matematic al pendulului inversat (IP), se analizeaza cateva configuratii conventionale ca : modelul acrobot, pendubot, dublu-inversor si robotul biped cu componente elastice. Acest model este studiat in cazul unei arhitecturi speciale cunoscuta in literatura xa „robotul atlet", pentru care , elementele terminale ale picioarelor au configuratii particulare elastice, C-shaped elastic leg. Este determinat modelul echivalent al acestei arhitecturi mecanice si sunt propuse solutii de conducere bazate pe controlere liniare de tip LQR, PD sau solutii neliniare de tip „sliding mode control" ierarhizate. Parametrii optimi de acordare a acestor controlere sunt determinati prin algoritmi genetici.

Studiul dinamic al locomotiei este dezvoltat prin analiza fuctiilor de salt ale robotilor pasitori bipezi cu picioare „C-shaped leg".Sunt propuse solutii clasice pentru obtinerea performantelor dorite ale functiei de salt si sunt investigate cateva controlere bazate pe utilizarea lichidelor electrorheologice (ER).

O atentie deosebita este acordata simularii traiectorilor de miscare pentru diferite solutii de conducere si descrierii platformelor experimentale si rezultatelor testelor efectuate.

Un capitol de concluzii si de identificare a unor viitoare directii de cecetare incheie prezenta teza.

Cuprins

Capitolul 1 : PENDULUL INVERS:MODEL DE BAZA IN SISTEMUL ROBOT

Modelul pendul invers (IP) este o configuratie de baza in controlul robotilor (Robege 1960) Schaefer si Cannon (1966), Furuta et al. (1991) au dezvoltat teoria acestor modele [1]. Ulterior Furuta a dezvoltat modelul pendulului dublu cu actionare rotativa [2]. [3] . Solutiile propuse au fost extinse de numerosi autori atat sub raportul performantelor mecanice cat si al sistemelor de conducere. [4], [5].

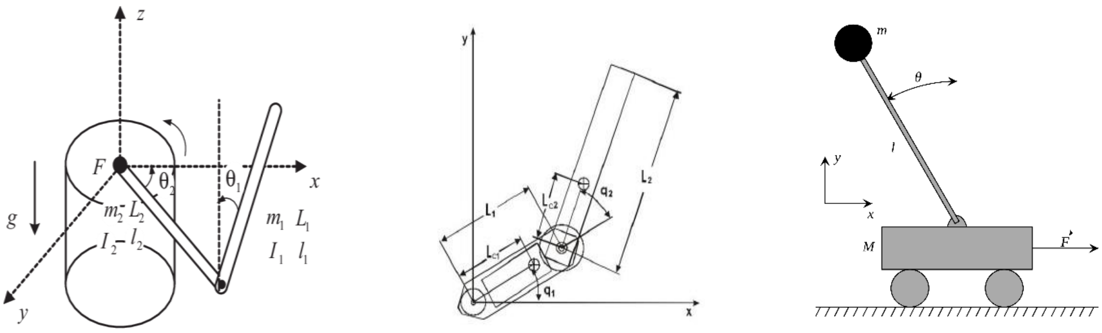

Fig 1.3 : Modele bazate pe configuratii IP

In principiu, algoritmii de control testati se bazeaza pe identificarea solutiilor de control ale pozitiilor de echilibru in modelele IP. Au sost, de asemenea , adoptate si solutii clasice bazate pe conventionale controlere PD sau PID [64], [65], [68] sau control liniar LQR [36], [14], bazat pe tehnici consacrate de repartitie poli-zerouri. Avantajul acestor tehnici rezida in simplitatea lor in conditiile in care tehnicile de performana se bazeaza pe metode de interpretare a erorii. Un interes aparte l-au jucat sistemele de conducere de tip fuzzy. Desi performantele obtinute nu sunt intotdeauna la nivelul droit, simplitatea acestor controlere si facilitate tehnicilor de Implementare au facut ca solutiile de acest tip sa fie preferabile in multe tehnici experimentale. [69]. O clas aparte de controlere abordeaza neliniaritatile intriseci configuratiei mecanice prin metode „ sliding mode control” [70]. O tehnica superioara rezida in structurarea unor controlere hibride ce combina atat tehnicile sistemelor

inteligente cat si controlerele neliniare ierarhizate [18], [19], [59], [70].

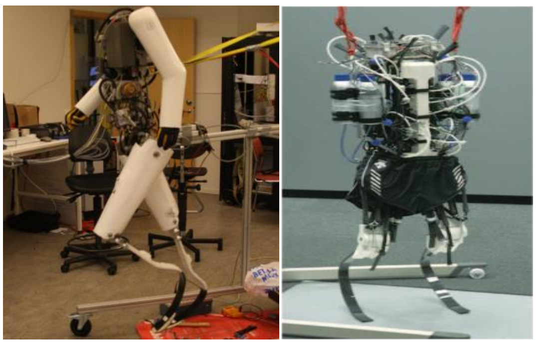

Figure 1.1: Robotul Dasher si modelul Universitatii din Tokyo

Capitolul 2: DINAMICA PENDULULUI INVERS

Modelul clasic IP a permis dezvoltarea unor configuratii cu arhitectura superioara, ce contin un numar mare de articulatii, cum ar fi pendulul dublu IP , sau structura de tip pendubot sau acrobot. Pentru toate aceste modele, obtinerea solutiilor de conducere cere determinarea cat mai exacta a modelului dinamic. In continuare vor fi analizate cateva modele de acest tip, incepand cu modelul IP on cart (Cart and Pole system) in care un carucior asigura deplasarea orizontala a sistemului rotativ al bratului.

a) Caz 1: Pendul cu masa distribuita (Fig 2.1)

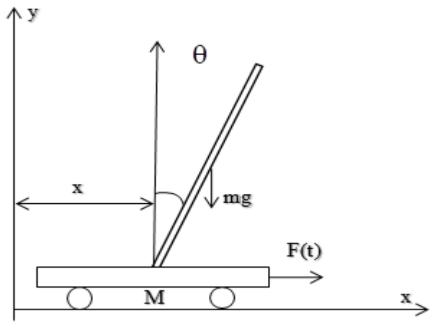

Figura 2.1: Sistemul „cart and Pole „ cu masa distribuita.

Modelul dynamic este definit ca

$$\ddot{x} = \frac{1}{\Gamma_1 + \Gamma_2 \sin^2\theta}\left[\Gamma_2 \sin\theta\left(L\dot{\theta}^2 - g\cos\theta\right) + F\right] \tag{2.1}$$

$$\ddot{\theta} = \frac{1}{L\left(\Gamma_1 + \Gamma_2 \sin^2\theta\right)}\left[-\Gamma_2 L\dot{\theta}^2 \sin\theta\cos\theta + \left(\Gamma_1 + \Gamma_2\right) g\sin\theta - F\cos\theta\right] \tag{2.2}$$

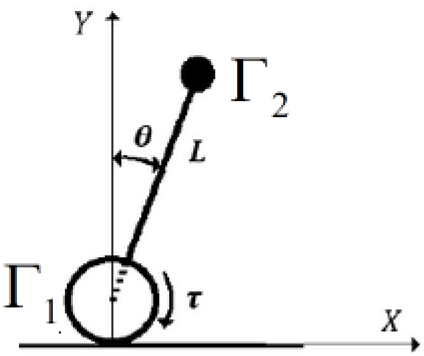

Figure 2.2: Balancing robot on wheel

Ecuatia de balans este:

$$\ddot{x} = \frac{\Gamma_2 \sin\theta\left(L\dot{\theta}^2 - g\cos\theta\right) + \tau/r}{\Gamma_1 + \Gamma_2 \sin^2\theta} \tag{2.3}$$

$$\ddot{\theta} = \frac{-\Gamma_2 L\dot{\theta}^2 \sin\theta\cos\theta + \left(\Gamma_1 + \Gamma_2\right) g\sin\theta - \tau\cos\theta / r}{L\left(\Gamma_1 + \Gamma_2 \sin^2\theta\right)} \quad (2.4)$$

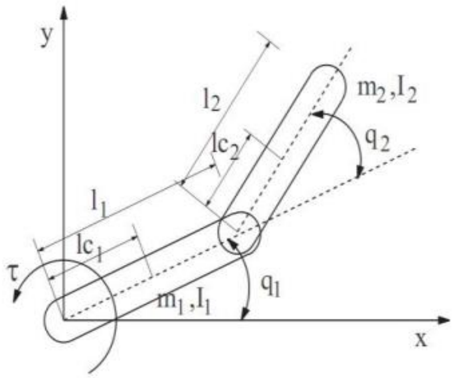

Figura 2.3: Structura unui Pendubot

Ecuatiile dinamice ale pendubot sunt

$$\ddot{q}_1 = \frac{\left[\begin{array}{l}\beta_2\tau_1 + \beta_2\beta_3\left(x_2 + x_4\right)^2 \sin x_3 + \beta_3^2 x_2^2 \sin x_3 \cos x_3 + \\ -\beta_2\beta_4 g\cos x_1 + \beta_3\beta_5 g\cos x_3 \cos\left(x_1 + x_3\right)\end{array}\right]}{\beta_1\beta_2 - \beta_3^2 \cos^2 x_3} \quad (2.5)$$

$$\ddot{q}_2 = \frac{\left[\begin{array}{l}\left(-\beta_2 - \beta_3\cos x_3\right)\tau_1 + \beta_4 g\left(\beta_2 + \beta_3\cos x_3\right)\cos x_1 + \\ -\beta_3\left(\beta_2 + \beta_3\cos x_3\right)\left(x_2 + x_4\right)^2 \sin x_3 + \\ -\beta_5 g\left(\beta_1 + \beta_3\cos x_3\right)\cos\left(x_1 + x_3\right) - \beta_3 x_2^2 \sin x_3\left(\beta_1 + \beta_3\cos x_3\right)\end{array}\right]}{\beta_1\beta_2 - \beta_3^2 \cos^2 x_3} \quad (2.6)$$

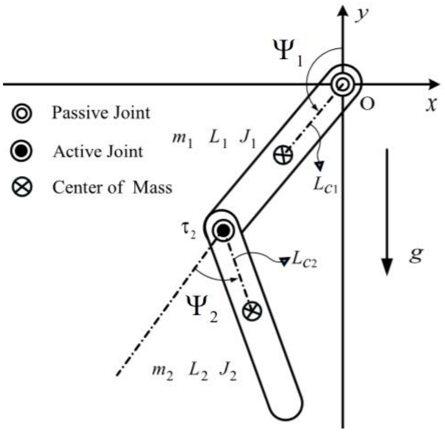

Figura 2.4: Structura unui acrobot

Neglijand frictiunea sistemului, se obtin urmatoarele ecuatii:

$$\frac{d}{dt}\left[\frac{\partial L(\Psi,\dot{\Psi})}{\partial \dot{\Psi}_i}\right]-\frac{\partial(\Psi,\dot{\Psi})}{\partial \Psi_i}=\tau_i,\left(i=1,2\right) \qquad (2.7)$$

Considerand $\tau_1 = 0$, (2.7) devines

$$M(\Psi_2)\ddot{\Psi}+C(\Psi,\dot{\Psi})\dot{\Psi}+G(\Psi)=\left[0 \quad \tau_2\right]^T \qquad (2.8)$$

Capitolul 3: ALGORITMI DE TIP LYAPUNOV PENTRU MODELE DE PENDUL INVERS

3.1. Metoda Lyapunov pentru modelul Cart and Pole

Teorema 3.1: Pentru modelul dynamic asociat, daca legea de control este

$$u = \frac{\sigma_1}{\varepsilon_1} x_1 + \frac{\sigma_2}{\varepsilon_2} x_2 \tag{3.1}$$

Unde coeficientii $\sigma_1 > 0$, $\sigma_2 > 0$, α, β, γ satisfac urmatoarele conditii:

$$\sigma_1 > \varepsilon_{1\max} \tag{3.2}$$

$$\sigma_1 + \sigma_2 \delta > \alpha + \varepsilon_{1\max} \beta \tag{3.3}$$

$$\left(\varepsilon_{1\min} - \sigma_1\right)\delta + \frac{1}{4}\left(\sigma_1 + \sigma_2 \delta - \alpha - \varepsilon_{1\max}\beta\right) < 0 \tag{3.4}$$

$$\delta - \sigma_1 \beta + \varepsilon_2 \beta + \varepsilon_2 \beta \eta_1 \eta_2 + \sigma_1 + \sigma_2 \delta - \alpha - \varepsilon_{1\max} \beta < 0 \tag{3.5}$$

$$\alpha > \frac{\delta}{4} > 0 \tag{3.6}$$

$$\beta > 2\delta \tag{3.7}$$

Sistemul este exponential stabil.

3.2. Control robust

Se considera modelul dynamic al sistemului IP de forma

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \varepsilon_1 & -\varepsilon_2 x_1 x_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ -\varepsilon_3 \end{bmatrix} u \tag{3.8}$$

Unde restrictii de stare de tip sector sunt definite ca

$$-\eta_1 \le x_1 \le \eta_1; \qquad -\eta_2 \le x_2 \le \eta_2 \tag{3.9}$$

Teorema 3.2: Se considera modelul IP (3.8) si legea de conducere

$$u = -ky \tag{3.10}$$

Unde rangul variabilelor este constrans de (3.9)

Daca parametrii γ, k, c_1, c_2, c_3, c_4, c_5, c_6 satisfac conditiile

$$0 < \gamma \le 4 \tag{3.11}$$

$$0 < k < \frac{1}{2\sqrt{\gamma}} \quad (3.12)$$

$$0 \leq \gamma + 2\,\mathrm{Re}\left\{\left(\frac{C}{2}\right)^T (j\omega I - A)^{-1} B\right\} \quad (3.13)$$

Atunci sistemul este asimptotic stabil

3.3. Algoritmi fuzzy-Lyapunov pentru modele IP

Sa considera sistemul IP descries ca:

$$\dot{x} = \Delta f(x) + f(x) + (b + \Delta b)u\,,\ x(0) = x_0 \quad (3.14)$$

unde: $\Delta f(x)$ si Δb reprezinta incertitudinea lui $f(x)$ si b, respectiv

Modelul fuzzy este descris de r regului fuzzy. Regula l este

If z_1 is F_{i1} and z_2 is F_{i2} and … and z_p is F_{ip} then

$$\dot{x} = \left(B^i + \Delta B^i\right)u + \left(A^i + \Delta A^i\right)x \quad (3.15)$$

$$F_{ij}(x_i) = \begin{cases} 1 - \dfrac{\left|x_i - j_i\tilde{\Delta}\right|}{\tilde{\Delta}} & \left|x_i - j_i\tilde{\Delta}\right| < \tilde{\Delta} \\ 0 & elsewhere \end{cases} \quad (3.16)$$

<u>Teorema 3.3:</u> SE considera a lege PD si k defineste matricea de reactie. Daca urmatoarele conditii sunt verificate

a) $k_{\min} \leq k \leq k_{\max}$

b) $\mathrm{Re}\left\{c^T (j\omega I - H)^{-1} \hat{b}\right\} + \left(k_{\max}^{-1} - \varepsilon^{-1}\beta\right) \geq 0$

unde $H = \left(A^1 + \nu I - k_{\min}M\right)$ este o matrice Hurwitz iar $\hat{b} = b^1 - d/k$

c) Perechea $\left(H, \hat{b}\right)$ este controlabila

Atunci modelul este asimptotic stabil.

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Capitolul 4: CONTROL FUZZY PENTRU MODELE DE PENDUL INVERS

4.1. Controler fuzzy bazat pe Lyapunov.

Se considera modelu IP discutat anterior si se selecteaza o functie Lyapunov de forma

$$V = \frac{1}{2}\left(\alpha x_1^2 + \beta x_2^2 + 2\delta x_1 x_2\right) \geq \frac{1}{2}\left[\left(\alpha - \frac{\delta}{2}\right)x_1^2 + \left(\beta - 2\delta\right)x_2^2\right] \quad (4.1)$$

Derivata in raport cu timpul va fi

$$\dot{V} = \chi - \varepsilon_3 \vartheta u \quad (4.2)$$

unde $\chi = 5\varepsilon_1 x_1 x_2 + 2x_2^2 - 5\varepsilon_2 x_1 x_2^3 - 2\varepsilon_2 x_1^2 x_2^2 + 2x_1 x_2$; $\vartheta = 2x_1 + 5x_2$

Controlerul fuzzy va realiza conditia ca derivata (4.2) sa fie negativ definita..

Table 1: Selection condition of control signal to satisfy Lyapunov criterion

Conditia de variabila			Conditia de control
$\vartheta > 0$	$x_1 x_2 > 0$	$\chi \geq 0$	$u \geq \chi / (\varepsilon_{3\min} \vartheta)$
		$\chi < 0$	$u \geq \chi / (\varepsilon_{3\max} \vartheta)$
	$x_1 x_2 < 0$	$\chi \geq 0$	$u \geq \chi / (\varepsilon_{3\min} \vartheta)$
		$\chi < 0$	$u \geq \chi / (\varepsilon_{3\max} \vartheta)$
$\vartheta < 0$	$x_1 x_2 > 0$	$\chi \geq 0$	$u \leq \chi / (\varepsilon_{3\min} \vartheta)$
		$\chi < 0$	$u \leq \chi / (\varepsilon_{3\max} \vartheta)$
	$x_1 x_2 < 0$	$\chi \geq 0$	$u \leq \chi / (\varepsilon_{3\min} \vartheta)$
		$\chi < 0$	$u \leq \chi / (\varepsilon_{3\max} \vartheta)$

Functiile de apartenenta pentru x_1 si x_2 sunt aratate in Figura 4.1 si Figure 4.2. Functia de apartenenta a iesirii este prezentata in Fig 4.3

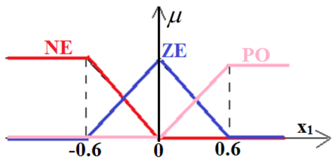


Figura 4.1: Functia de apartenenta pentru x_1

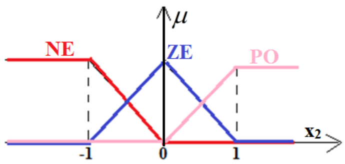


Figure 4.2: Functia de apartenenta pentru x_2

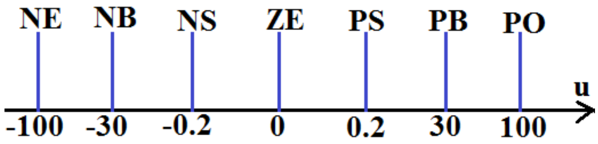


Figure 4.3: **:** Functia de apartenenta pentru iesire

4.2. Controler hibrid.

Sliding Mode Control reprezinta o tehnica foarte buna pentru implementarea unor controlere neliniare intr-o structura ierarhizata. [54]-[58].

Se considera modelul IP sub forma

$$\ddot{\alpha}_i = A_i(\alpha_i) + B_i(\alpha_i)u \qquad (4.3)$$

unde α_i, α_{di} : sunt variabile de stare iar u : este semnalul de control

Se defineste: $e_i = \alpha_i - \alpha_{di}$ (4.4)

Eroarea de urmarire

Din (4.3), (4.4) ecuatiile echivalente vor fi

$$\ddot{e}_i = f_i + g_i u \qquad (4.5)$$

Controlerul asociat lui (4.5) va stabiliza variabilele $e_i \xrightarrow{t\to\infty} 0$ sau $\alpha_i \xrightarrow{t\to\infty} \alpha_{id}$.

In Figura 4.4, este prezentata structura ierarhica asociata.

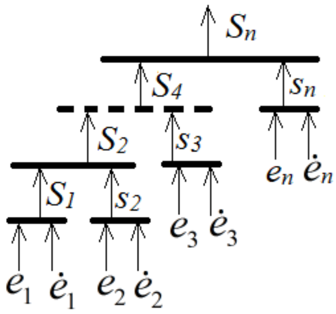


Figura 4.4: Suprafete sliding ierarhizate

Suprafetele sliding sunt

$$s_k = c_k e_k + \dot{e}_k \quad (k \le n) \qquad (4.6)$$

$$S_k = a_{k-1} S_{k-1} + s_k \quad (k \le n) \qquad (4.7)$$

unde $a_{i-1} = const$; $a_0 = S_0 = 0$.

$$S_k = \sum_{r=1}^{k} \left(\prod_{j=r}^{k} a_j \right) s_r \ \left(k \le n\right) \tag{4.8}$$

Pe nivelul k se obtine

$$u_k = u_{k-1} + u_{eqk} + u_{swk} \ \left(k \le n\right) \tag{4.9}$$

Controlul final este

$$u_n = \frac{\left[\sum_{r=1}^{n} \left(\prod_{j=r}^{n} a_j \right) b_r u_{eqr} - \eta_n \operatorname{sgn} S_n - \xi_n S_n \right]}{\sum_{r=1}^{n} \left(\prod_{j=r}^{n} a_j \right) b_r} \tag{4.10}$$

Capitolul 5: MODELE DE PENDUL INVERSE CU COMPONENTE ELASTICE

5.1. Pendulul invers elastic

In capitolele anterioare, modelul adoptat pentru pendulul elastic (E-IP) era de tipul modelului cu parametrii concentrati. In realitate, exista o distributie spatiala a parametrilor modelului ceea ce face ca o interpretare ma exacta sa fie cea in care sistemul este descris prin ecuatii cu distributie spatiala a variabilelor.

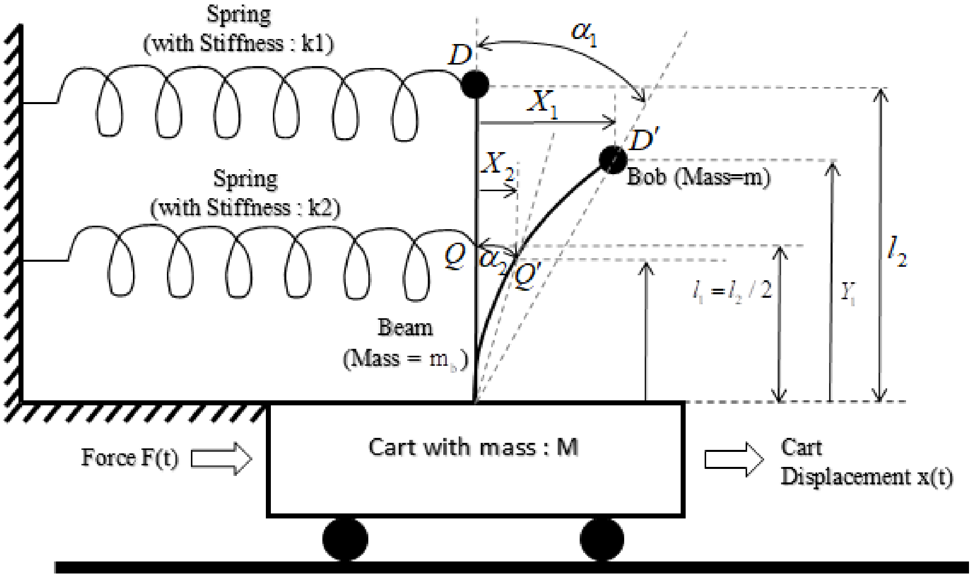


Figure 5.1: E-IP

Un astfel de model este prezentat in Fig 5.[73]-[75].

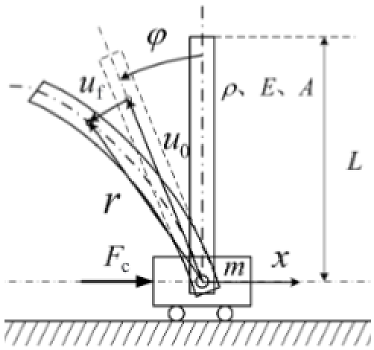


Figure 5.2: E-IP pe Cart fix

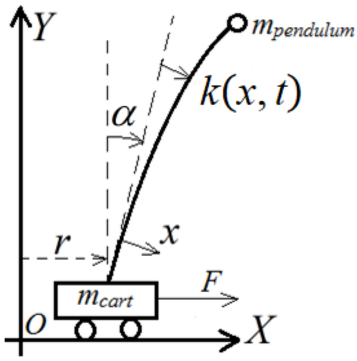


Figure 5.3: E-IP model

Conform principiului lui Hamilton

$$\int_{t_1}^{t_2}\left(\delta T-\delta V+\delta W_{nc}\right)dt=0$$

unde δT , δV , δW_{nc} reprezinta componentele variationale ale energiilor cinetice , potentiale si lucrul fortelor neoconservative.

Modelul dinamic va fi

$$-\left(m_{cart}+\rho l+m_{pendulum}\right)\ddot{r}-\left(m_{pendulum}l+\rho\frac{l^2}{2}\right)\ddot{\alpha}\cos\alpha+$$

$$+m_{pendulum}\begin{bmatrix}\ddot{\alpha}\times k(l,t)\sin\alpha-\dot{k}(l,t)\times\cos\alpha+\\+2\dot{\alpha}\times\dot{k}(l,t)\sin\alpha+\dot{\alpha}^2\times k(l,t)\times\cos\alpha\end{bmatrix}+$$

$$+\left(\rho\frac{l^2}{2}+m_{pendulum}l\right)\dot{\alpha}^2\sin\alpha+\rho\int_0^l\begin{pmatrix}\ddot{\alpha}k\times\sin\alpha-\ddot{k}\times\cos\alpha+\\+2\dot{\alpha}\dot{k}\times\sin\alpha+\dot{\alpha}^2k\times\cos\alpha\end{pmatrix}dx+F=0$$

$$-\left(J+m_{pendulum}l^2+\rho\frac{l^3}{3}\right)\ddot{\alpha}-\left(m_{pendulum}l+\rho\frac{l^2}{2}\right)\ddot{r}\times\cos\alpha+$$

$$+m_{pendulum}\begin{bmatrix}\ddot{r}k(l,t)\times\sin\alpha-\ddot{\alpha}k^2\times(l,t)-l\ddot{k}(l,t)+\\-2\dot{\alpha}\times k(l,t)\times\dot{k}(l,t)+gk(l,t)\times\cos\alpha\end{bmatrix}+$$

$$+\rho\int_0^l\left(\ddot{r}k\times\sin\alpha-\ddot{\alpha}k^2-\ddot{k}x-2\dot{\alpha}k\dot{k}+gk\times\cos\alpha\right)dx+$$

$$+\left(m_{pendulum}gl+\rho g\frac{l^2}{2}\right)\sin\alpha=0$$

$$m_{pendulum}\left[k(l,t)\times\dot{\alpha}^2-\ddot{k}(l,t)-l\ddot{\alpha}-\ddot{r}\times\cos\alpha+g\sin\alpha\right]+EI\times k'''(l,t)=0$$

$$\rho\left(k\dot{\alpha}^2-\ddot{k}-\ddot{\alpha}x-\ddot{r}\times\cos\alpha+g\times\sin\alpha\right)-EI\times k''''=0$$

$$k'''(0,t)=k''(0,t)=k''(l,t)=0$$

Se defnesc $\Psi_i(t)$, $X_i(x)$ functiile associate modului I si $k(x,t)$ se considera ca $k(x,t)=\sum_{i=1}^{n}\Psi_i(t)X_i(x)$ [76]. Considerand modul de rang 1, se obtine

$$-\left(m_{cart}+\rho l+m_{pendulum}\right)\ddot{r}-\left(m_{pendulum}l\rho\frac{l^2}{2}\right)\ddot{\alpha}\cos\alpha+m_{pendulum}\begin{bmatrix}X(l)\Psi\ddot{\alpha}\sin\alpha+\\ -X(l)\dot{\Psi}\cos\alpha+\\ +2X(l)\dot{\Psi}\dot{\alpha}\sin\alpha+\\ +X(l)\Psi\dot{\alpha}^2\cos\alpha\end{bmatrix}+ \qquad (5.6)$$

$$+\left(\rho\frac{l^2}{2}+m_{pendulum}l\right)\dot{\alpha}^2\sin\alpha+\rho\xi_1\Psi\ddot{\alpha}\sin\alpha-\rho\xi_1\ddot{\Psi}\cos\alpha+2\rho\xi_1\dot{\Psi}\dot{\alpha}\sin\alpha+$$

$$+\rho\xi_1\Psi\dot{\alpha}^2\cos\alpha+F=0$$

$$-\left(J+m_{pendulum}l^2+\rho\frac{l^3}{3}\right)\ddot{\alpha}-\left(m_{pendulum}l+\rho\frac{l^2}{2}\right)\ddot{r}\cos\alpha+\rho g\xi_1\cos\alpha\Psi+ \qquad 7)$$

$$+\left(m_{pendulum}gl+\rho g\frac{l^2}{2}\right)\sin\alpha+m_{pendulum}\begin{bmatrix}X(l)\Psi\ddot{r}\sin\alpha-X^2(l)\Psi^2\ddot{\alpha}+\\ -X(l)\ddot{\Psi}l-2X^2(l)\Psi\dot{\Psi}\dot{\alpha}+\\ +X(l)\Psi g\cos\alpha\end{bmatrix}+$$

$$+\rho\xi_1\ddot{r}\Psi\sin\alpha-\rho\xi_2\Psi^2\ddot{\alpha}-\rho\xi_3\ddot{\Psi}-2\rho\xi_2\Psi\dot{\Psi}\dot{\alpha}=0$$

$$m_{pendulum}\left[X(l)\Psi\dot{\alpha}^2-X(l)\ddot{\Psi}-l\ddot{\alpha}-\ddot{r}\cos\alpha+g\sin\alpha\right]+\xi_4\Psi=0 \qquad 8)$$

5.2. Modele elastice C-shaped Leg.

C-haped leg reprezinta o structura elastica ce asigura o mai buna elasticitate a configuratiilor picioarelor

Figure 5.4: Bara curbata

Forfecare: $F_r=F\cos\theta$ (5.9)

Axial: $F_\theta=F\sin\theta$ (5.10)

Moment de incovoiere: $M=FR\sin\theta$ (5.11)

Energia momentului M este

$$U_1=\int\frac{M^2}{2AeE}d\theta \qquad (5.12)$$

unde e este excentricitatea $e = R - r_n$. Daca $R/h > 10$, rezulta

$$U_1 = \int \frac{M^2 R}{2EI} d\theta \qquad (5.13)$$

Energia datorata fortei axiale F_θ este

$$U_2 = \int \frac{F_\theta^2 R}{2AE} d\theta \qquad (5.14)$$

Energia fortei F

$$U_4 = C \int \frac{F_r^2 R}{2AG} d\theta \qquad (5.15)$$

Conform legii lui Hook

$$F = k\delta \qquad (5.16)$$

unde k este constanta elastica echivalenta iar δ este deflexia..

Pentru C-shaped leg, parametrul k este variabil in lungul arcului de curba.

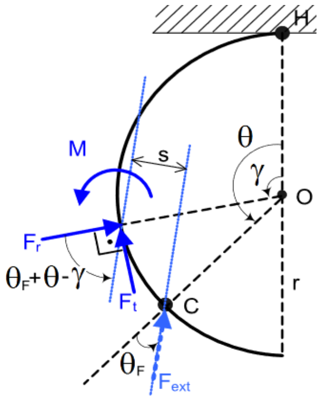


Figura 5.5: Sectiune transversala in C-shaped leg

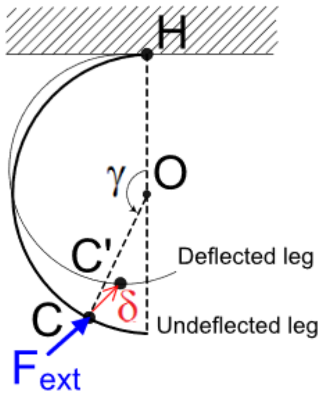
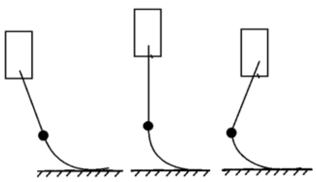


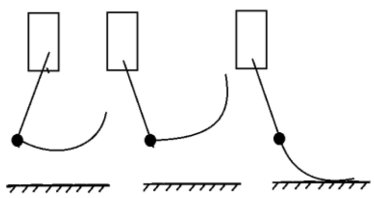
Figura 5.6: efectul fortei externe inC-shaped leg

5.3. Controlul unui Robot C-shaped Leg prin metode Lyapunov

Analizand miscarea unui robot cu doua picioare, distingem doua faze: stance and flight phase. In stance phase, picioarele sunt in contact cu solul, ifaza flight, picioarele nu au contact cu solul.



Stance phase



Fight phase

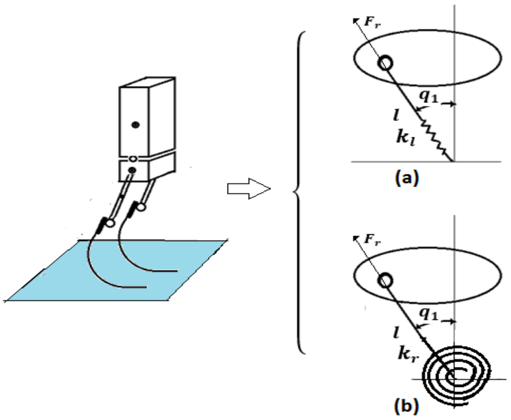


Figure 5.7: Modelul IP al unui robot cu picioare C-shaped leg:
a/ linear model/b)rotational model

Deflectia rotationala este

$$\delta_r \approx \frac{\partial U}{\partial M} \qquad (5.17)$$

Se obtine

$$k_l \approx \frac{M}{\delta_l} = \frac{4EI}{R^2\left\{\pi + \frac{1}{2}\left[\sin(2\varphi) + \sin(2[\pi - \varphi])\right]\right\}}$$

Modelul dinamic va fi

$$\left(M^* l^2 + I^*\right)\ddot{q}_1 = M^* gl \sin q_1 - k_r(\varphi) q_1 + \tau_1^* + h(\tau_2, \tau_3, q_2, q_3) \qquad (5.18)$$

Se propune un controler PD

$$\tau = -\mu_1 q_1 - \mu_2 \dot{q}_1 \qquad (5.19)$$

<u>Teorema 5.1:</u> Daca sistemul (5.19) este supus legii de control (5.20) iar parametrii de control verifica

$$\sqrt{\frac{k_r}{\mathbb{N}}} > \alpha > 0\,,\ \eta > 0 \qquad (5.20)$$

$$\mu_1 > 0\,;\ \mu_2 > 0 \qquad (5.21)$$

$$\begin{bmatrix} \mu_2 - \alpha\mathbb{N} - \eta & \frac{1}{2}(\mu_2 + \alpha\mu_2 - mgl) \\ \frac{1}{2}(\mu_1 + \alpha\mu_2 - mgl) & \alpha\left(k_{r\max} + \mu_1 - mgl - \eta\right) \end{bmatrix} > 0 \qquad (5.22)$$

Sistemul este asymptotic stabil.

Capitolul 6: ALGORITMI DE CONTROL AL MISCARII DE SALT

Sistemul din Fig 6.1 este format din doua picioare articulate in modul C-shaped leg in care sistemul de actionare este caracterizat de:

- Partea inferioara cu actionare hibrida electro hidraulica/pneumatica cu fluid ER.
- Componenta superioara cu actionare electrica conventionala.

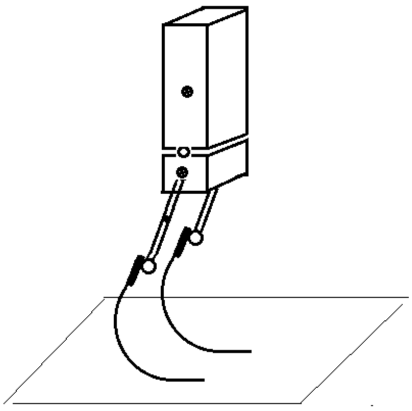


Figura 6.1: Modelul unui robot de salt

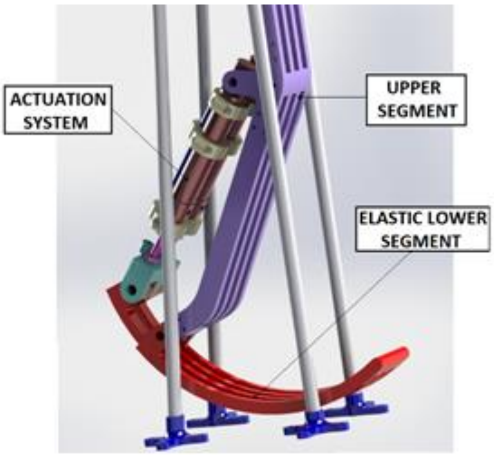


Figure 6.2: Platforma robotului de salt

Miscarea robotului este determinata de cele doua faze: faza stance cand piciorul este in contact cu solul si faza flight cand acesta paraseste solul. Frontiera intre cele doua faze este delimitata de secventele: touch-down , cand se obtine primul contact cu solul , si take-off, cand piciorul se desprinde de sol. Aceste secvente se executa periodic in cadrul ciclului de miscare.

6.1. Modelul Stance Phase

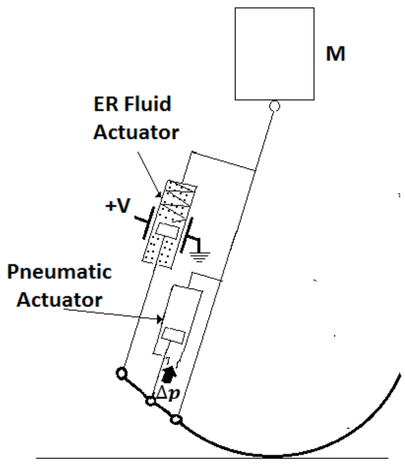


Figure 6.3: mechanical structure of leg for jumping robot

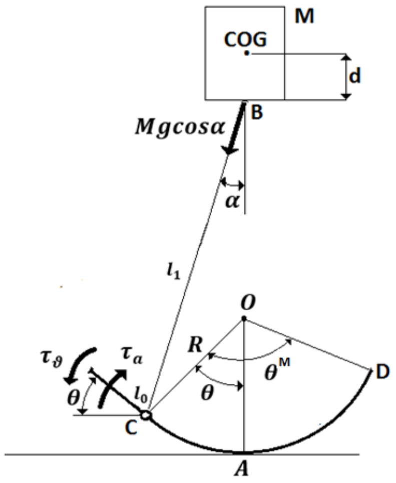


Figure 6.4: mathematical structure of leg for jumping robot

Modelul dinamic este

$$M\left(d+l_1\right)^2\ddot{\theta}+MgR\sin\theta+2EI\theta+\tau_\vartheta=\tau_a-\vartheta_0\dot{\theta} \qquad (6.1)$$

Cu conditia initiala

$$\theta(0)=\theta_0 \qquad (6.2)$$

sau

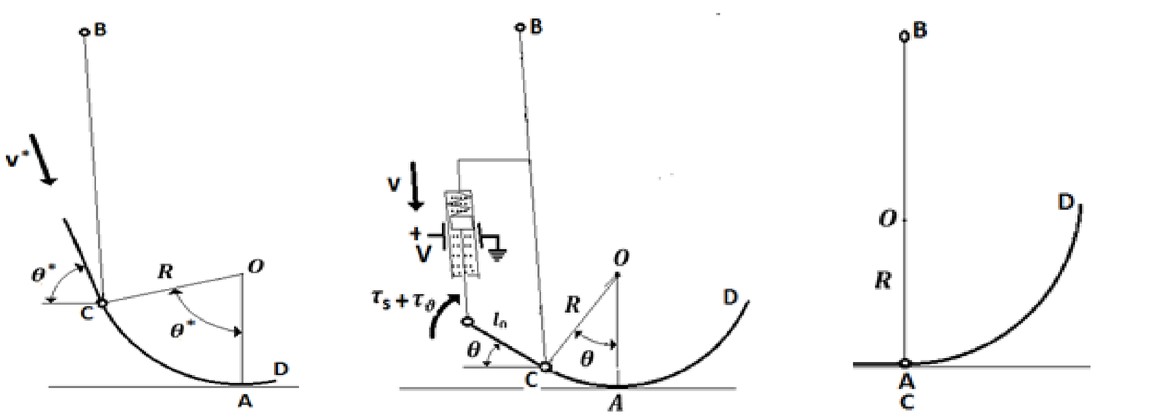
$$M\left(d+l_1\right)^2\ddot{\theta}+J\ddot{\theta}+\vartheta_0\dot{\theta}+K_e\theta=\tau_a-\tau_\vartheta \qquad (6.3)$$

Unde coeficientul dinamic echivalent este

$$K_e=MgR+2EI \qquad (6.4)$$

6.2. Secventa Stance Phase: Touch-Down

Calitatea miscarii determinata de cativa coeficienti de performanta constituie o cerinta primordiala in aceasta faza. Contactul cu solul determina oscilatii ale intregului sistem ceea ce impune gasirea unor metode adecvate de ameliorare a indicilor de calitate. In acest scop, sistemul de amortizare este prevazut cu un sistem hydraulic cu lichid ER iar investigarea regimului de miscare este bazata pe tehnici de tip skyhook. .(fig 6.5-6.7)



Touch-Down Sequence Initial State

Touch-Down Sequence Intermediate State

Touch-Down Sequence Final State

Figure 6.5: Touch-Down Sequence

<u>Case 1:</u> Actuator ca sistem passive damper

Modelul Touch-Down este ilustrat in **Error! Reference source not found.** unde K_f , K_s definesc coeficientii elastici ai piciorului si resortului..

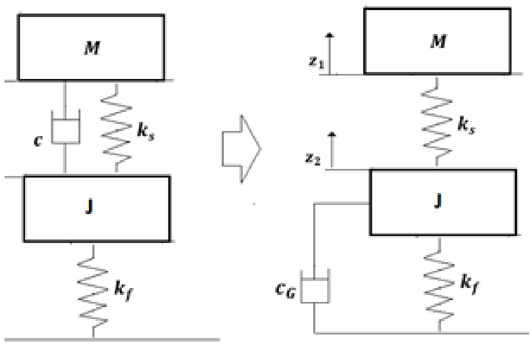


Figure 6.6: Ground-hook damper model

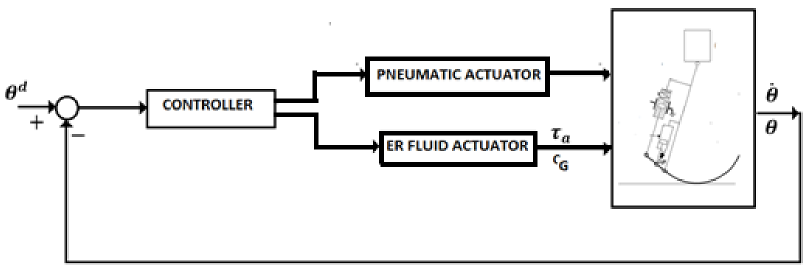


Figure 6.7: Sistemul de controlal secventei Touch-Down

Modelul dinamic este

$$\ddot{\theta}J = -\vartheta_0\dot{\theta} - MgR\sin\theta - 2EI\theta + K_S\left(z_1 - z_2\right)R^* + c\left(\dot{z}_1 - \dot{z}_2\right) \qquad (6.5)$$

unde z_1, z_2 reprezinta coordonatele verticale ale celor doua conexiuni (B, C); K_S

si R^* sunt coeficientii elastici si raza echivalenta de miscare

$$R^* = l_0 \cos\theta + R\sin\theta \quad (6.6)$$

unde c este coeficient de amortizare pasiv.

Transmisibilitatea sistemului este [96].

$$T(\omega) = z_2(\omega) / z_1(\omega) \quad (6.7)$$

unde

$$z_1 = l_0 \sin\theta + R(1-\cos\theta) + l_1 \cos\alpha \quad (6.8)$$

$$z_2 = l_0 \sin\theta + R(1-\cos\theta) \quad (6.9)$$

Presupunand oscilatii mici in jurul punctului de echilibru

$$\left| R\theta / l_0 \right| < 1 \quad (6.10)$$

atunci

$$z_2 \approx l_0\theta \quad (6.11)$$

$$R^* \approx l_0 \quad (6.12)$$

Substituing **Error! Reference source not found.**) , **Error! Reference source not found.**) in **Error! Reference source not found.**), se obtine

$$\ddot{z}_2 = -\frac{\vartheta_0 + c_G}{J}\dot{z}_2 - \frac{MgR + 2EI + K_S l_0^2}{J} z_2 + \frac{K_S l_0^2}{J} z_1 + \frac{c l_0^2}{J}\dot{z}_1 \quad (6.13)$$

Aplicand transformarea Laplace rezulta

$$T(s) = \frac{z_2(s)}{z_1(s)} = \frac{K_S l_0^2 + \frac{c l_0^2}{J} s}{s^2 + \frac{\vartheta_0 + c_G}{J} s + \frac{MgR + 2EI + K_S l_0^2}{J}} \quad (6.14)$$

Substiting $s = j\omega$ in **Error! Reference source not found.**, se obtine

$$T(j\omega) = \frac{z_2(j\omega)}{z_1(j\omega)} = \frac{1 + 2\zeta(j\omega/\omega_n)}{-1 + (\omega/\omega_n)^2 + 2\zeta(\omega/\omega_n) j} \quad (6.15)$$

unde ω_n este frecventa naturala a sistemului

$$\omega_n = \sqrt{\frac{MgR + 2EI + K_S l_0^2}{J}} \quad (6.16)$$

iar ζ factorul de amortizare pasiv

$$\zeta_p = \frac{\vartheta_0 + c}{2\sqrt{J\left(MgR + 2EI + K_S l_0^2\right)}} \tag{6.17}$$

<u>Case 2:</u> Actuator ca damper semiactiv (ground system)

O strategie "Groundhook" (in **Error! Reference source not found.**) se propune pentru studiul regimului oscilator. Se considera un coeficient

$$c_G = \begin{cases} c_{\max}\dot{z}_2 & if \quad -\dot{z}_2\left(\dot{z}_1 - \dot{z}_2\right) > 0 \\ c_{\min}\dot{z}_2 & if \quad -\dot{z}_2\left(\dot{z}_1 - \dot{z}_2\right) < 0 \end{cases} \tag{6.18}$$

Se obtine

$$\ddot{z}_2 = -\frac{\vartheta_0 + c_G}{J}\dot{z}_2 - \frac{MgR + 2EI + K_S l_0^2}{J} z_2 + \frac{K_S l_0^2}{J} z_1 \tag{6.19}$$

sau

$$T\left(s\right) = \frac{z_2\left(s\right)}{z_1\left(s\right)} = \frac{K_S l_0^2}{s^2 + \frac{\vartheta_0 + c_G}{J} s + \frac{MgR + 2EI + K_S l_0^2}{J}} \tag{6.20}$$

$$T\left(j\omega\right) = \frac{z_2\left(j\omega\right)}{z_1\left(j\omega\right)} = \frac{\eta}{-1 + \left(\frac{\omega}{\omega_n}\right)^2 + 2\zeta_G \frac{\omega}{\omega_n} j} \tag{6.21}$$

unde ω_n si ζ_G sunt definiti ca

$$\zeta_G = \frac{\vartheta_0 + c_G}{2\sqrt{J\left(MgR + 2EI + K_S l_0^2\right)}} \tag{6.22}$$

$$\eta = \frac{K_S l_0^2}{MgR + 2EI + K_S l_0^2} \tag{6.23}$$

<u>Caz 3:</u> Actuator ca sistem ER Driver

Dinamica actuatorului este

$$\ddot{\theta} J = -\vartheta_0\dot{\theta} - MgR\sin\theta - 2EI\theta + K_S\left(z_1 - z_2\right)R^* + c_\vartheta\left(\dot{z}_1 - \dot{z}_2\right) + \tau_a \tag{6.24}$$

sau

$$\ddot{\theta} = -\frac{\vartheta_0 + c_\vartheta l_0^2}{J}\dot{\theta} - \frac{MgR + 2EI + K_S l_0^2}{J}\theta + \frac{K_S l_0}{J} z_1 + \frac{c_\vartheta l_0}{J}\dot{z}_1 + \frac{1}{J}\tau_a \tag{6.25}$$

Se definesc variabilele de stare

$$\begin{cases} x = \begin{bmatrix} x_1 & x_2 \end{bmatrix}^T = \begin{bmatrix} \theta & \dot{\theta} \end{bmatrix}^T \\ \quad z = \begin{bmatrix} z_1 & z_2 \end{bmatrix}^T \end{cases} \tag{6.26}$$

Dinamica sistemului devine

$$\dot{x} = Ax + b\tau_a + Dz \tag{6.27}$$

$$y = c^T x \tag{6.28}$$

unde

$$A = \begin{bmatrix} 0 & 1 \\ -\dfrac{MgR + 2EI + K_S l_0^2}{J} & -\dfrac{\vartheta_0 + c_\vartheta l_0^2}{J} \end{bmatrix};\ b = \begin{bmatrix} 0 \\ \dfrac{1}{J} \end{bmatrix};\ D = \begin{bmatrix} 0 & 0 \\ \dfrac{K_S l_0}{J} & \dfrac{c_\vartheta l_0}{J} \end{bmatrix}$$

Perturbaria este evaluata in termeni de variabile de stare ca

$$z_1 = \alpha\theta \ (\alpha < \alpha^*) \tag{6.30}$$

$$z_2 = \beta\dot{\theta} \ (\beta < \beta^*) \tag{6.31}$$

und α , β sunt constante pozitive. mOdelul dinamic (6.27) devine

$$\dot{x} = A^* x + b\tau_a \tag{6.32}$$

unde

$$A^* = \begin{bmatrix} 0 & 1 \\ -\dfrac{MgR + 2EI + K_S l_0^2}{J} + \alpha & -\dfrac{\vartheta_0 + c_\vartheta l_0^2}{J} + \beta \end{bmatrix} \tag{6.33}$$

Se propune o lege de conducere

$$\tau_a = -ky \tag{6.34}$$

unde $k = const > 0$ satisface o conditie de sector

$$k_{\min} \le k \le k_{\max} \tag{6.35}$$

<u>Teorema 6.1:</u> Starea $\begin{bmatrix} x_1 & x_2 \end{bmatrix}^T = \begin{bmatrix} \theta & \dot{\theta} \end{bmatrix}^T$ converge la 0 daca urmatoarele conditii sunt satisfacute:

a) Matrice $H = A^* - E$ este Hurwitz, unde $E = ec^T$ este o matrice simetrica.

b) (H, b) este controlabila si (H, c) este observabila.

c) $\mathrm{Re}\left\{\frac{c^T}{2}(sI-H)^{-1}\left(b-ek^{-1}\right)\right\}+k^{-1}\geq 0$ (6.36)

<u>Remark 6.1:</u>

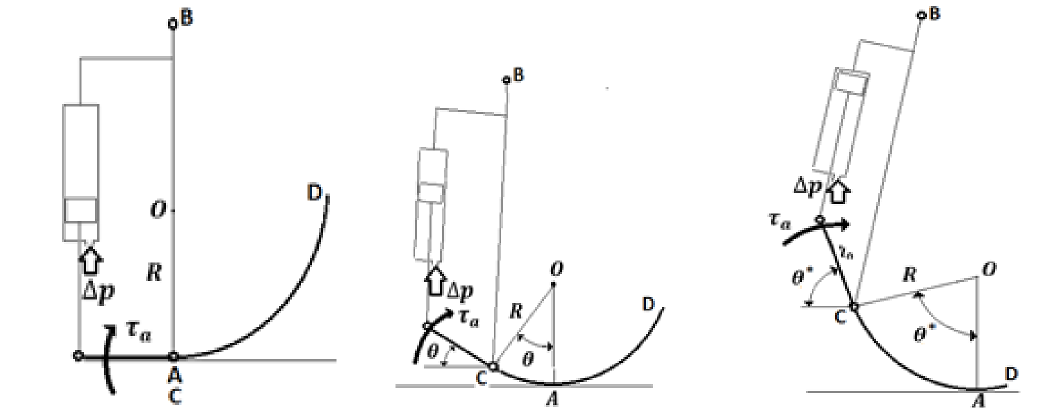
Se defineste functia de transfer $G(s)$

$$G(s)=\frac{c^T}{2}(sI-H)^{-1}\left(b-ek^{-1}\right) \qquad (6.37)$$

Considerand **Error! Reference source not found.** si conditia c) a Teoremei 6.1 se obtine criteriul cercului[98]

$$\mathrm{Re}\left(\frac{k_{\max}^{-1}+G(j\omega)}{k_{\min}^{-1}+G(j\omega)}\right)>0 \qquad (6.38)$$

6.3. Secventa Stance Phase: Take-off



Take-off Sequence Initial State | Take-off Sequence Intermediate State | Take-off Sequence Final State

Figura 6.8: Secventa Take-off

In timpul acestei secvente, actuatorul dezvolta suficienta energie pentru a asigura evolutia pe traiectorie

$$W(t)\geq W^{*} \qquad (6.39)$$

$$\frac{dW(t)}{dt}\geq\gamma>0 \qquad (6.40)$$

unde $W(0)=0$ iar W^{*} este energia critica ce determina evolutia pe traiectorie, $\gamma=const>0$ ..

Se defineste υ^{*} viteza de start pe traiectorie la $\theta=\theta^{*}$ (in **Error! Reference source not found.**c). Energia critica va fi

$$W^* = \frac{1}{2} K_f \left(\theta^*\right)^2 + \frac{1}{2 l_0^2} J \left(\dot{\theta}^*\right)^2 \qquad (6.41)$$

Iar energia totala

$$W = w^T w = \frac{1}{2} K_f \theta^2 + \frac{1}{2} J \dot{\theta}^2 \qquad (6.42)$$

Unde primul termen corespunde energiei elastice inmagazinata in picior.

$$w = \begin{bmatrix} \dfrac{\theta}{\sqrt{\dfrac{2}{K_e}}} & \dfrac{\dot{\theta}}{\sqrt{\dfrac{2}{J}}} \end{bmatrix}^T$$

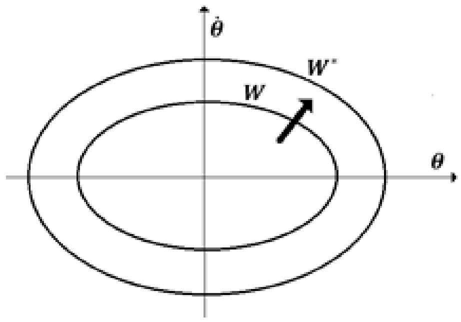


Figura 6.9: Elipsoid de energie

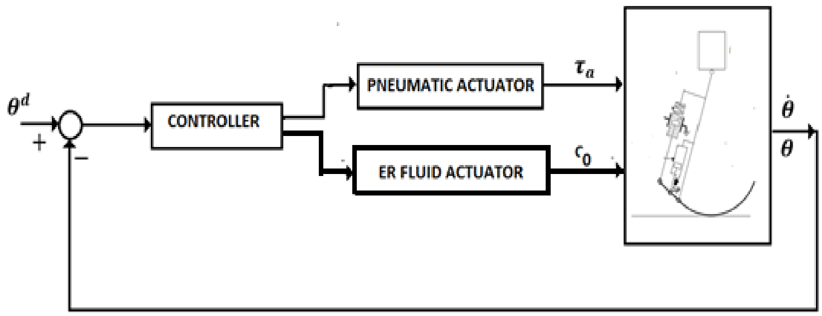


Figure 6.10: Controlul secventei Take-off

Theorem 6.2: Conditiile de salt **Error! Reference source not found.**) si **Error! Reference source not found.**) sunt satisfacute daca legea de control este

$$\tau_a = -k_1^J \theta + k_2^J \dot{\theta} \qquad (6.44)$$

unde k_1^J , k_2^J sunt constante pozitive ce satisfac

$$k_1^J > K_f - K_e \qquad (6.45)$$

$$2k_2^J - k_1^J > 2\left(\vartheta_0 + c_0\right) - K_f + K_e \qquad (6.46)$$

Capitolul 7: SIMULAREA ALGORITMILOR DE CONTROL

7.1. Simularea controlului LQR pe modelul E-IP.

Se considera modelul E-IP si un controler LQR in care parametrii matricilor sunt selectati prin tehnici GA. Rezultatele simularii sunt prezentate in Fig7.1, Fig 7.2

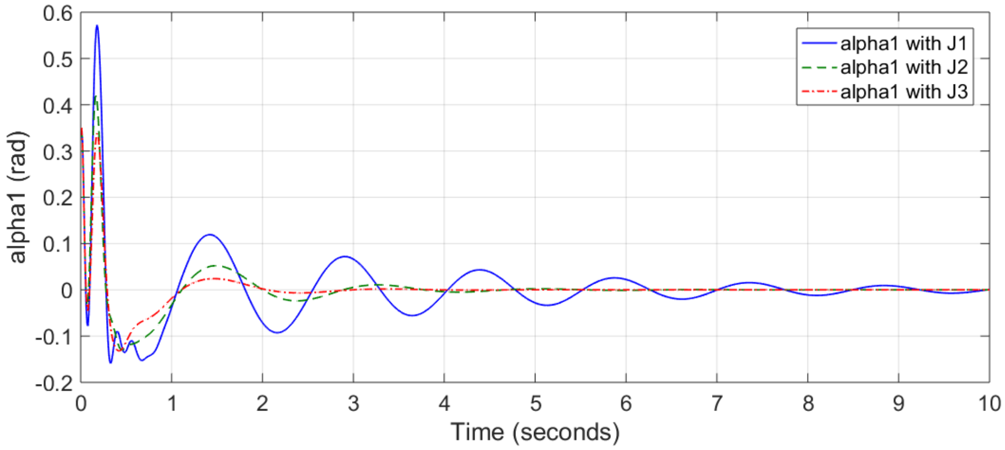


Figura7.1: Comparatia raspunsurilor modelului E-IP prin controler LQR pentru α_1 (rad)

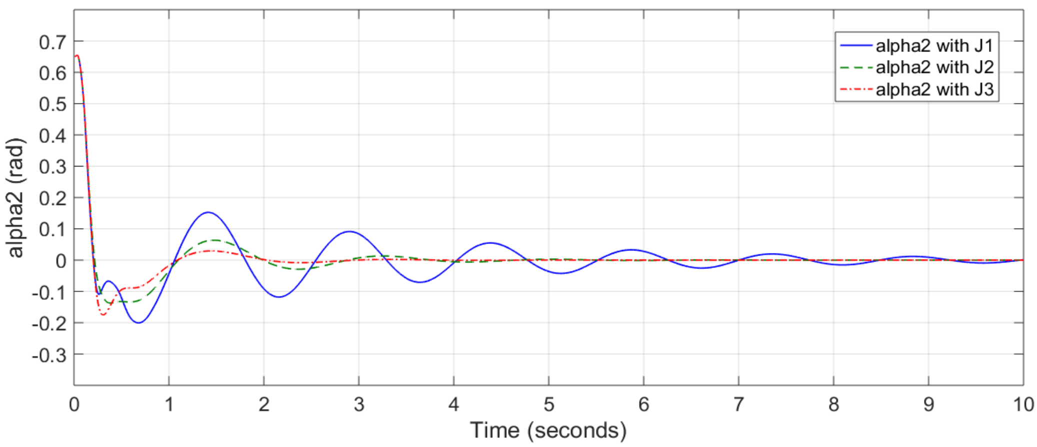


Figure 7.2: Comparatia raspunsurilor modelului E-IP prin controler LQR pentru α_2 (rad)

7.2. Control HSM pentru sistem E-IP

Se considera un control

$$u = \frac{\left(a_1 a_2 g_1 u_{eq1} + a_2 g_2 u_{eq2} + g_3 u_{eq3}\right) - \left(k_3 S_3 + \eta_3 signS_3\right)}{a_1 a_2 g_1 + a_2 g_2 + g_3}$$

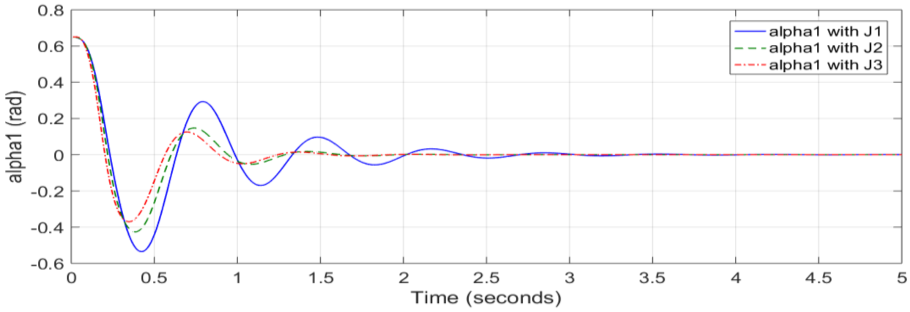


Figure 7.3: Comparatia raspunsurilor modelului E-IP prin controler HSM pentru α_1 (rad)

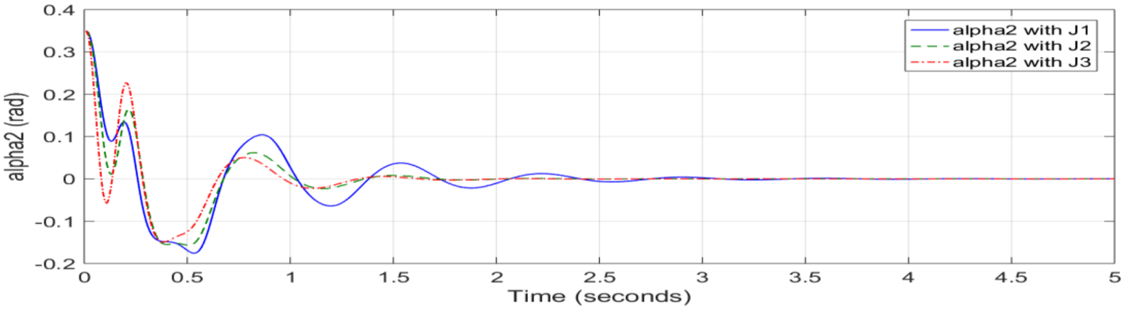


Figure 7.4: Comparatia raspunsurilor modelului E-IP prin controler HSM pentru α_2 (rad)

7.3. Control Conventional PD pentru robot biped.

Se considera un control Pd pentru robotul biped analizat (Fig 7.5).

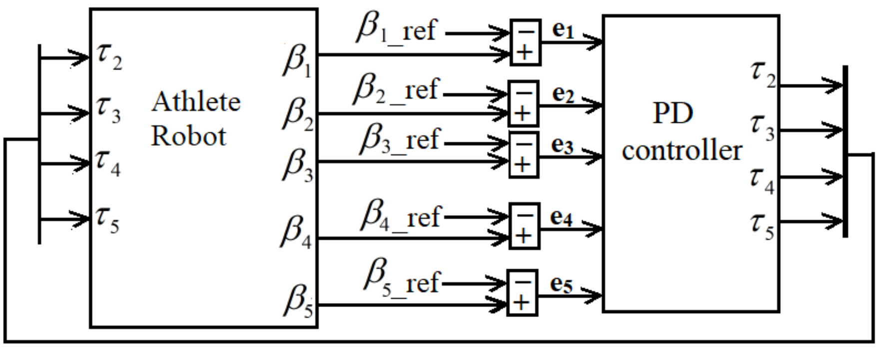


Figura 7.5: Sistemul de control

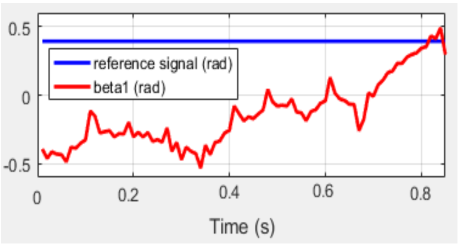


Figure 7.6: Reference signal β_{1_ref} and β_1

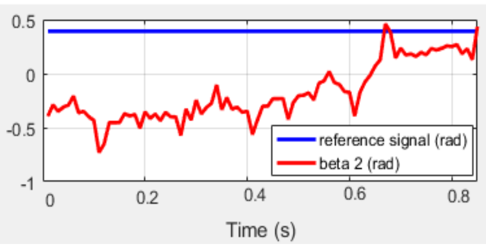


Figure 7.7: Reference signal β_{2_ref} and β_2

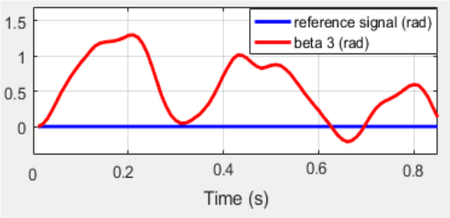


Figure 7.8: Reference signal β_{3_ref} and β_3

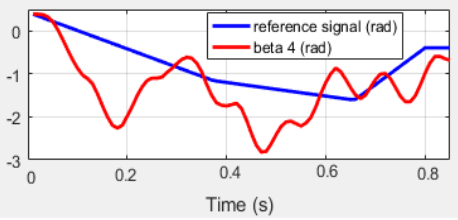


Figure 7.9: Reference signal β_{4_ref} and β_4

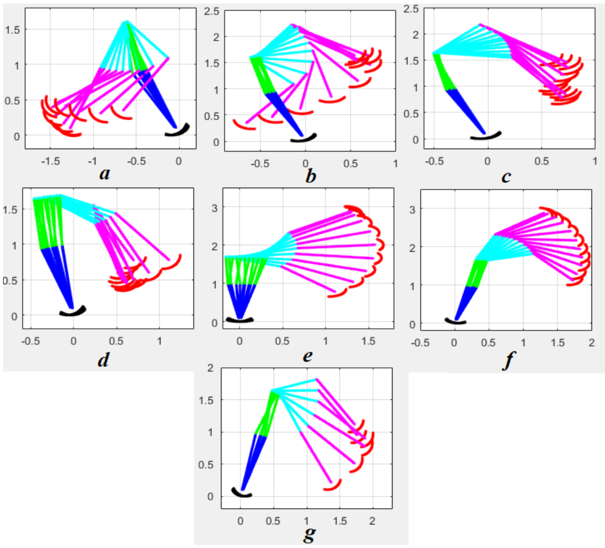
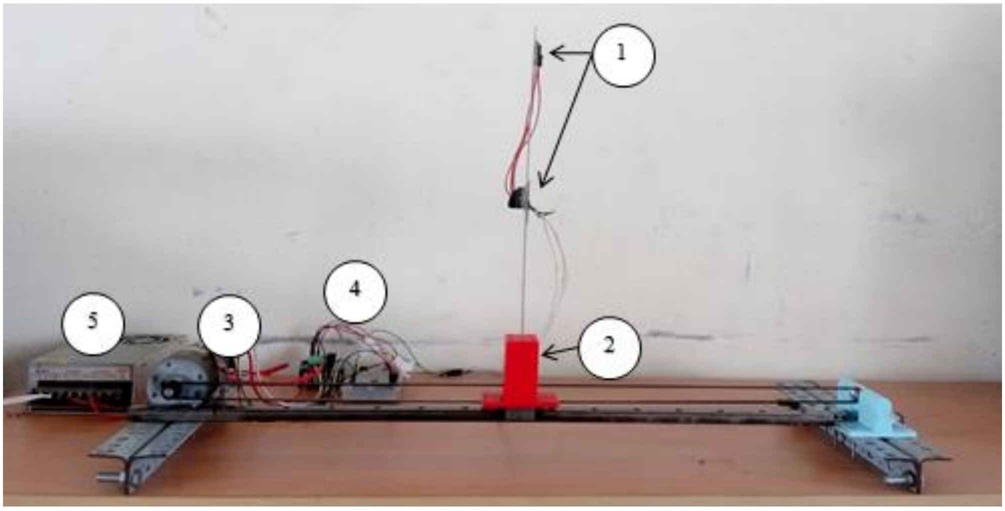


Figure 7.10**:** Miscarea robotului AR

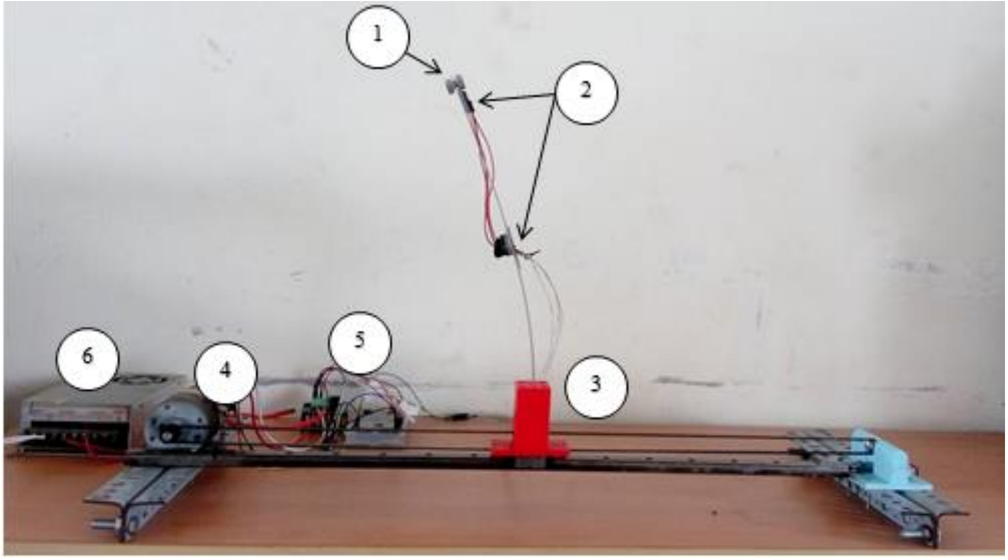
Capitolul 8: STUDIU EXPERIMENTAL AL MODELELOR CU COMPONENTE ELASTICE

8.1. Pendulul elastic invers

Platforma experimentala este prezentata in Fig 8.1



(a)



(b)

Figure 8.1: Platforma experimentala E-IP

8.2. Robot biped cu picioare elastice

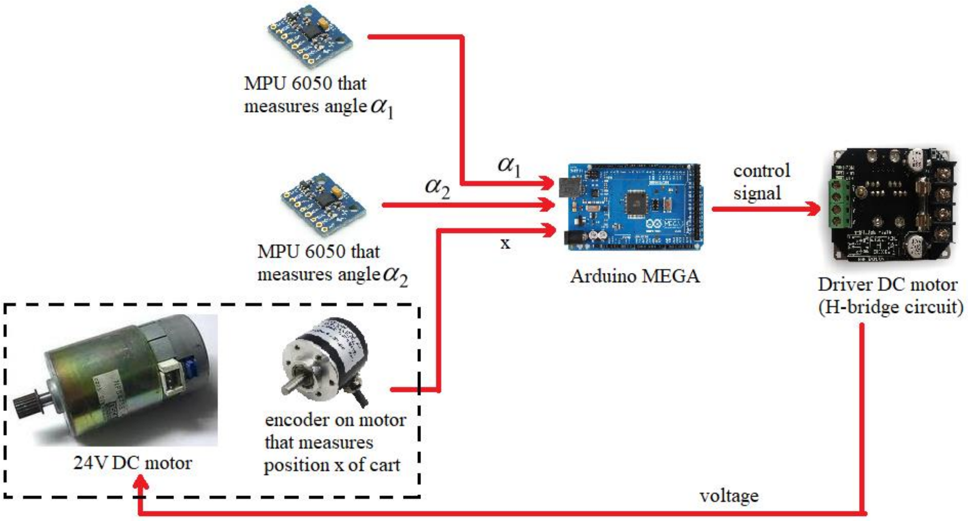


Figure 8.2Sistemul electronic

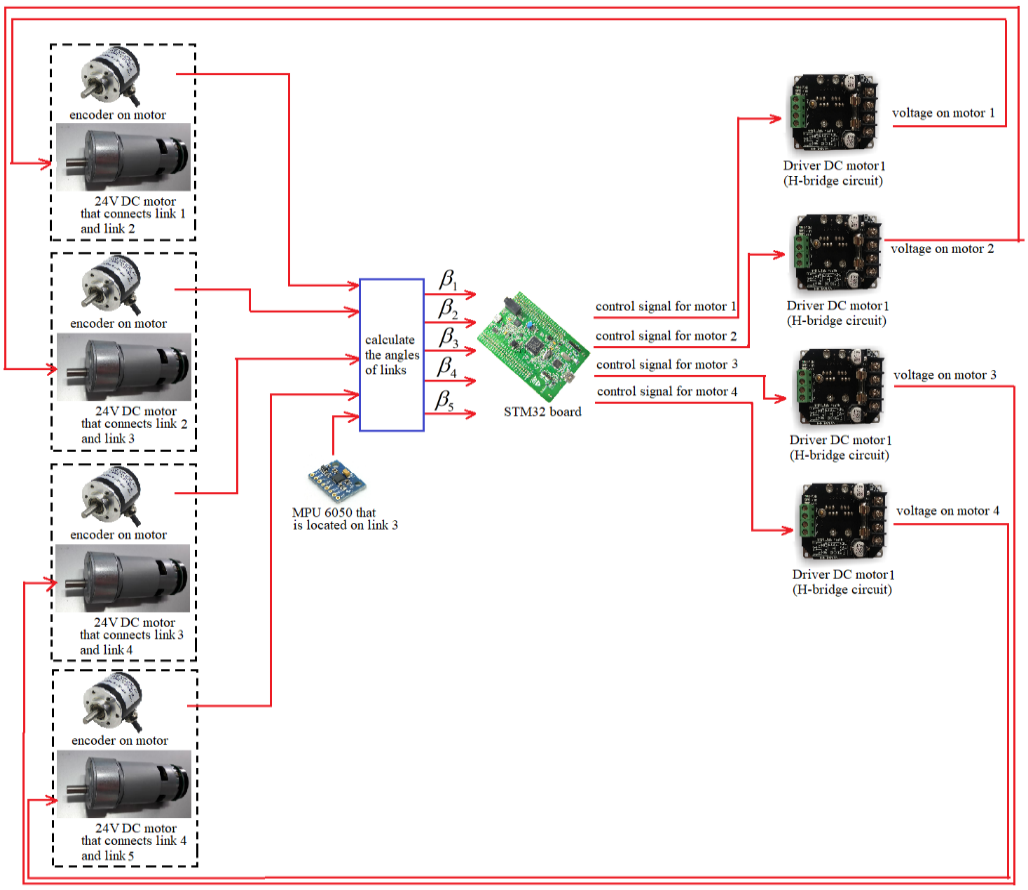


Figure 8.3: Structura fhardware

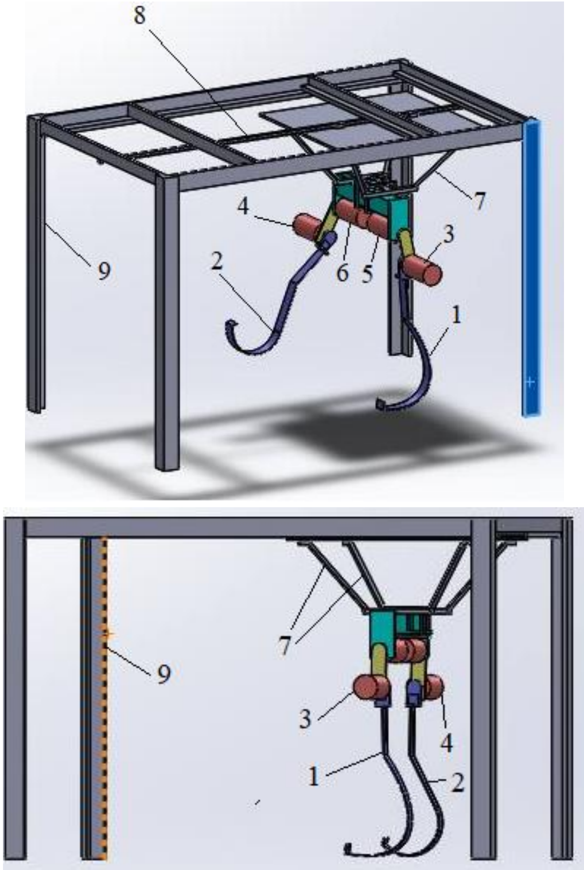


Figure 8.4: Model experimental in Solidworks

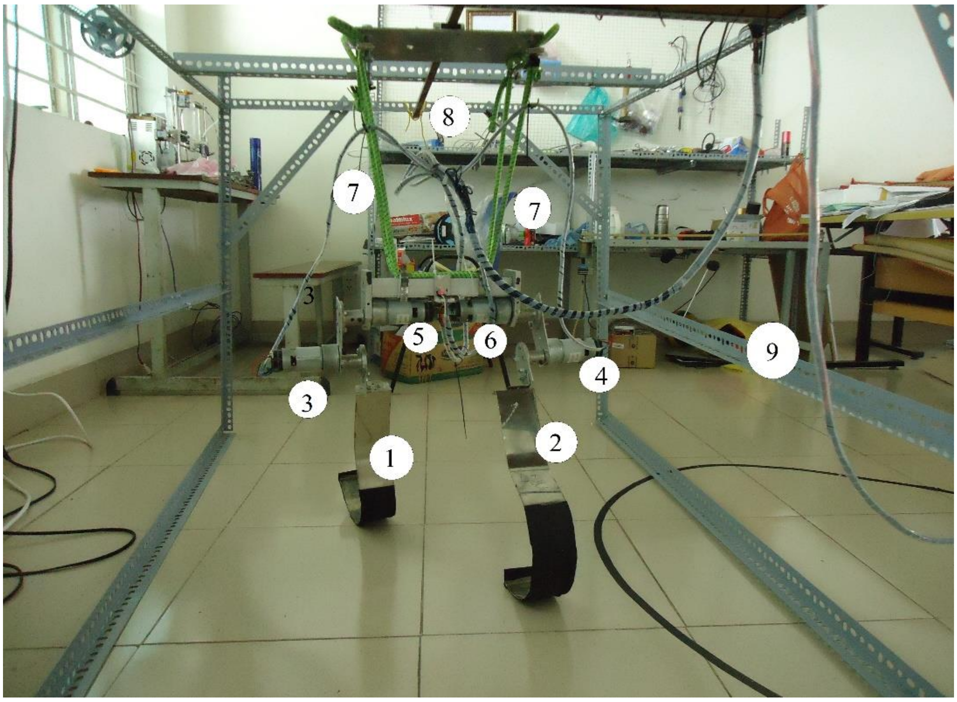


Figure 8.5: Imagine experimentala

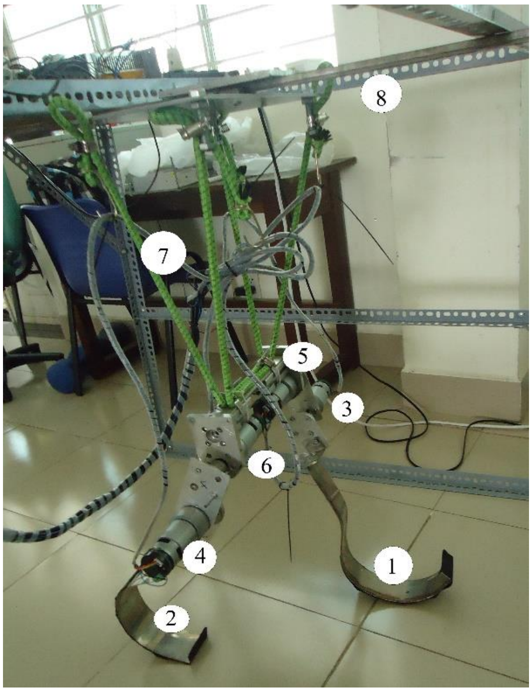


Figure 8.6: Imagine (foto) experiment

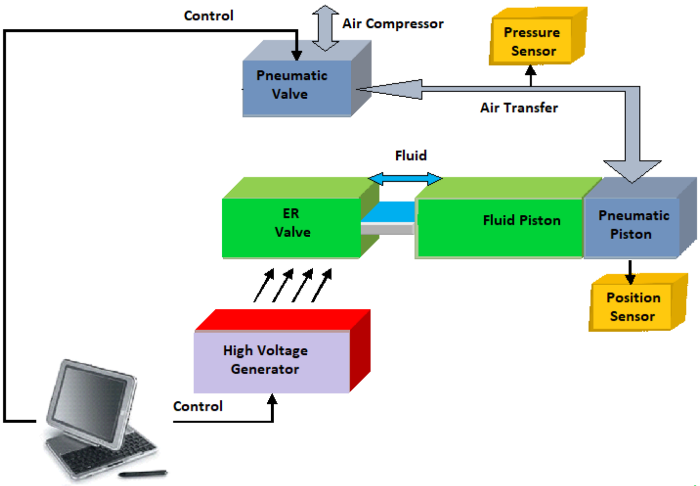


Figure 8.7: Platforma experimentala a arhitecturii de salt (Photo)

REFERENCE

[1] Kent H. Lundberg, Taylor W. Barton, "History of Inverted-Pendulum Systems", IFAC Proceedings Volumes, Vol. 42, Issue. 24, pp. 131-135, Elsevier, 2010.

[2] Furuta, K., Yamakita, M. and Kobayashi, S, "Swing-up control of IP using pseudo-state feedback", Journal of Systems and Control Engineering, 206(6), 263-269, 1992.

[3] Andrew Careaga Houck, Robert Kevin Katzschmann, Joao Luiz Almeida Souza Ramos, "Furuta Pendulum", Project of Advances System Dynamics & Control, Department of Mechanical Engineering, Massachusetts Institute of Techonology, Fall 2013.

[4] Olfar Boubaker, "The IP: a fundamental Benchmark in Control Theory and Robotics", pp 1-6, International Conference on Education and e-Learning Innovations (ICEELI), IEEE, 2012.

[5] Vo Anh Khoa, Nguyen Minh Tam, Le Thi Thanh Hoang, Nguyen Thien Van, **Nguyen Van Dong Hai,** "Model and Control Algorithm Construction for Rotary Inverted Pendulum in Laboratory", Journal of Technical Education and Science, ISSN: 18959-1272, 2018. (in Vietnamese) (accepted)

[6] US patent 5,701,965 Human transporter

[7] US Patent 6,302,230 Personal mobility vehicles and methods

[8] US patent 6,616,313 Motorized transport vehicle for a pedestrian

[9] Two-wheel, self-balancing vehicle with independently movable foot placement sections US 8738278 B2

[10] Patent USD739307 - One-wheeled vehicle

[11] R. Sethunadh, P. P. Mohanlal, "Virtual instrument based dynamic balancing system for rockets and payloads", Autotestcon, IEEE, pp. 291-296, 2007. DOI: 10.1109/AUTEST.2007.4374232

[12] Shuai Sun, Zhishan Zhang, Quan Pan, Cangan Sun, "Controller design for anti-heeling system in container ships", 35th Chinese Control Conference (CCC), pp. 5798-5803, IEEE, 2016. DOI: 10.1109/ChiCC.2016.7554263

[13] Pencheng Wang, Zhihong Man, Zhenwei Cao, Jinchuan Zheng, Yong Zhao, "Dynamics modelling and linear control of quadcopter", International Conference on Advanced Mechatronic Systems (ICAMechS), IEEE, 2016.

[14] Tran Vi Do, Ho Trong Nguyen, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "Balancing Control for Double-linked IP on Cart: Simulation and Experiment", Journal of Technical Education Science, ISSN: 1859-127, No. 44A, pp. 68-75, November-2017.

[15] V. Casanova, J. Salt, R. Piza, A. Cuenca, "Controlling the Double Rotary inverted pendulum with Multiple Feedback Delays", Vol. VII, No. 1, pp. 20-38, 2012.

[16] **Nguyen Van Dong Hai**, Nguyen Phong Luu, Nguyen Minh Tam, Hoang Ngoc Van, "Optimal Control for Quadruped inverted pendulum", pp. 18-23, Vol. 34, Journal of Technical Education Science, Vietnam, ISSN: 1859-1272, 2016.

[17] A. Gmiterko, M. Grossman, "N-link Inverted Pendulum Modelling", Recent Advances in Mechatronics, pp. 151-156, Recent Advances in Mechatronics, Springer 2017.

[18] Tran Hoang Chinh, Nguyen Minh Tam, **Nguyen Van Dong Hai,** "A Method of PID-FUZZY control for pendubot", Journal of Technical Education Science, No. 44A, pp. 61-67, ISSN: 1859-127, November-2017.

[19] Huynh Xuan Dung, Huynh Duong Khanh Linh, Vu Dinh Dat, Nguyen Thanh Phuong, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "Application of Fuzzy Algorithm in Optimizing Hierarchical SMC for Pendubot System", International Journal of Robotica & Management, Vol. 22, Nr. 2, Dec-2017.

[20] Scott C. Brown, Kevin M. Passino, "Intelligent Control for an Acrobot", Journal of Intelligent and Robotic Systems, No. 18, pp. 209-248, Netherlands, 1999.

[21] Umashankar Nagarajan, George Kantor, Ralph Hollis, "The ballbot: An omnidirectional balancing mobile robot", The International Journal of Robotics Research, 2013.

[22] Nguyen Minh Tam, **Nguyen Van Dong Hai**, Nguyen Phong Luu, Le Van Tuan, "Modelling and Optimal Control for Two-wheeled Self-Balancing Robot", Journal of Technical Education Science, Vietnam, ISSN: 1859-1272, Vol. 37, pp. 35-41, 2016.

[23] Nguyen Minh Hoang, Ngo Van Thuyen, Nguyen Minh Tam, Le Thi Thanh Hoang, **Nguyen Van Dong Hai**, "Desiging Linear Feedback Controller for E-IP with Tip Mass", International Journal of Robotica & Management, pp. 27-32, Vol. 21, Nr. 2, December-2016.

[24] Toshiyuki Hayase, Yoshikazu Suematsu, "Control of a flexible IP", Vol. 8, Issue. 1, Journal of Advanced Robotics, pp. 1-12, Taylor& Francis, 1993.

[25] Andrzej Kot, Agata Nawrocka, "Modeling of Human Balance as an IP", 15th International Carpathian Control Conference (ICCC), pp. 254-257, IEEE, 2014.

[26] Akihiro Sato, "A Planar Hopping Robot with One Actuator: Design, Simulation, and Experimental Results", Master thesis, McGill University, Canada, 2004.

[27] Ismail Uyamk, "Adaptive Control of a One-legged Hopping Robot through Dynamically Embedded Spring Loaded IP", Master thesis, Bilkent University, 2011.

[28] Patrick M. Wensing and David E. Orin, "Control of Humanoid Hopping Based on a SLIP Model", Advances in Mechanisms, Robotics and Design Education and Research, Part of the Mechanisms and Machine Science book series, pp. 265-274, Springer, 2013.

[29] Full, R. J. and Koditschek, D. E., "Templates and anchors: neuromechanical hypotheses of legged locomotion on land", Journal of Experimental Biology, 202(23):3325–3332, 1999.

[30] J. G. Ketelaar, L. C. Visser, S. Stramigioli and R. Carloni, "Controller Design for a Bipedal Walking Robot using Variable Stiffness Actuators", IEEE International Conference on Robotics and Automation (ICRA), pp. 5650-5655, IEEE, Germany, May-2013.

[31] Yiping Liu, “A Dual-SLIP Model for Dynamic Walking in a Humanoid over Uneven Terrain”, PhD thesis, Ohio State University, 2015.

[32] Yiping Liu, Patrick M. Wensing, James P. Schmiedeler, and David E. Orin, “Terrain-Blind Humanoid Walking Based on a 3D Actuated Dual-SLIP Model”, IEEE Robotics and Automation Letters, 2016.

[33] Mathew D. Berkerneier, Kamal V. Desai, “Design of a Robot Leg with Elastic Energy Storage, Comparison to Biology, adn Preliminary Experimental Results”, pp. 213-218, Proceedings of the 1996 IEEE International Conference on Robotics and Automatio, Minnepolis, 2016**.**

[34] Jerry E. Pratt, Benjamin T. Krupp, “Series Elastic Actuators for legged robots”, Proceedings of SPIE-The International Society for Optical Engineering, 2004. DOI:10.1117/12.548000

[35] Fantoni, I., Lozano, R., “Noninear Control for Under-actuated Mechanical System”, Springer-Verlag, London, 2002.

[36] Ho Trong Nguyen, Nguyen Minh Tam, **Nguyen Van Dong Hai**, “Application of Genetic Algorithm in Optimization Controller for Cart and Pole System”, Journal of Technical Education Science, ISSN: 1859-127, No. 44A, pp. 41-47, November, 2017.

[37] Nguyen Van Dong Hai, “Input-output Linearization controller for Cart and Pole system”, Master Thesis of Automation and Control, Ho Chi Minh city University of Technology (HCMUT), Vietnam, 2011.

[38] Beletzky V.V, “Nonlinear Effects in Dynamics of Controlled Two-legged Walking”, Part of Book of Nonlinear Dynamics in Engineering Systems, International Union of Theoretical and Applied Mechanics, pp. 17-26, Springer, 1990.

[39] Sujan, W., Amin, B., Nathan, S. & Madhavan, S, “Bipedal Walking – A Developmental Design”, In Proceedings of International Symposium on Robotics and Intelligent Sensors, Procedia 41, pp. 1016-1021, Elsevier, 2012.

[40] Qinghua, L., Takanishi, A. & Kato, I, “A Biped Walking Robot having a ZMP Measurement System using Universal Force-moment Sensors”, In *Proceeding of Intelligent Robots and System,* pp. 1568-1573, IEEE, 1991.

[41] Kim, D. W., Kim, N. H. & Park, G. T, “ZMP based Neuron Network Inspired Humanoid Robot Control”, *Journal of Nonlinear Dynamics, 67(1),* pp. 793-806. Springer, 2012.

[42] J. A. Smith & A. Seyfarth, “Elastic Leg Function in a Bipedal Walking Robot*”, Journal of Biomechanics*, Page S306, Vol. 40, Supplement 2, Elsevier, 2007.

[43] Maziar Ahmad Sharbafi, Christian Rode, Stefan Kurowski, Dorian Scholz, Rico Mockel, Katayon Radkhah, Goouping Zhao, Aida Mohammadinejad Rashty, Oskar von Stryk & Andre Seyfarth, “*A New Biarticular Actuator Design Facilities Control of Leg Function in BioBiped3*”, Journal of Bioinspiration & Biomimetics, Vol. 11, No. 4, IOP Publishing, 2016.

[44] Ryuma Niiyama, Satoshi Nishikawa, Yasuo Kuniyoshi, "Biomechanical Approach to Open-Loop Bipedal Running with a Musculoskeletal Athlete Robot", Journal of Advanced Robotics, Vol. 26, Issue. 3-4, 2012.

[45] Ryuma Niiyama and Yasuo Kuniyoshi, "Design of a Musculoskeletal Athlete Robot: A Biomachanical Approach", Proceedings of the Twelfth International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines, Turkey, 2009.

[46] Gianluca Garofalo, Christian Ott & Alin Albu-Schaffer, "Walking control of fully actuated robots based the Bipedal SLIP model", In *Proceeding of International Conference on Robotics and Automation (ICRA)*, pp. 1456-1463. IEEE, 2012.

[47] Mohammad Shabazi, Robert Babuska & Gabriel A. D. Lopes, "Unified Modeling and Control of Walking and Running on IP", IEEE Transactions of Robotics, Vol. 32, Issue 5, pp. 1178-1195, 2016.

[48] **Nguyen Van Dong Hai,** Mircea Ivanescu, Mircea Nitulescu, "Hierarchical Sliding Mode Control for Balancing Athlete Robot", 21st International Conference on System Theory, Control and Computing (ICSTCC 2017), Sinaia, Romania, Nov-2017.

[49] **Nguyen Van Dong Hai**, Huynh Xuan Dung, Nguyen Minh Tam, Cristian Vladu, Mircea Ivanescu, "Hierarchical Sliding Mode Algorithm for Athlete Robot Walking", Journal of Robotics, Article ID 6348980, Hindawi, December-2017. DOI: doi.org/10.1155/2017/6348980 (ISI/ESCI/SCOPUS journal)

[50] Castigliano A, "Elastic Stresses in Structures", Cambridge University Press, 2014.

[51] Endo, G., Morimoto, J., Nakanishi, J. & Cheng, G, "An Empirical Exploration of a Neural Oscillator for Biped Locomotion Control", In *Proceedings of International Conference on Robotics & Automation*, pp. 3036-3042. IEEE, 2004.

[52] Hein, D., Hild, M. & Berger, R, "Evolution of Biped Walking Using Neural Oscillators and Physical Simulation", *Part of the Lecture Notes in Computer Science book series (LNCS), Vol. 5001*, pp. 433-440. Springer, 2007.

[53] Lothar M. Schmitt, "Theory of genetic algorithms", Theoretical Computer Science, Vol. 259, Issues 1-2, pp. 1-61, Elsevier, May-2001.

[54] Dianwei Qian, Jianqiang Yi, Dongbin Zhao, Yinxing Hao, "Hierarchical Sliding Mode Control for Series Double Inverted Pendulum System", International Conference on Intelligent Robots and Systems, IEEE, 2006. DOI: 10.1109/IROS.2006.282521

[55] Dianwei Qian, Jianqiang Yi, Dongbin Zhao, "Hierarchical Sliding Mode Control for a Class of SIMO Under-actuated Systems", Journal Control and Cybernetics, Vol. 37, No. 1, 2008.

[56] Qian, Dianwei, Yi, Jiangqiang, "Hierarchical SMC for Under-actuated Cranes: Design, Analysis and Simulation", Book of Control Engineering, Springer-Verlag, 2016.

[57] Vu Duc Ha, Huynh Xuan Dung, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "Hierarchical Fuzzy Sliding Mode Control for a Class of SIMO Under-actuated Systems", Journal of Technical Education Science, ISSN: 1859-1272, Vietnam, 2017.

[58] Kamal Rsetam, Zhenwei Cao, Zhihong Man, "Hierarchical Sliding Mode Control applied to a single-link flexible joint robot manipulator", International Conference on Advanced Mechatronic Systems, IEEE, 2016.

[59] Vu Dinh Dat, Huynh Xuan Dung, Phan Van Kiem, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "A method of Fuzzy-Sliding Mode Control for Pendubot model", Journal of Science and Technology-University of Da Nang, Vietnam, ISSN: 1859-1591, No. 11 (120), Issue 1, pp. 12-16, 2017.

[60] E. Trillas, "Lotfi A. Zadeh: On the man and his work", Scientia Iranica, Volume 18, Issue 3, June 2011, Pages 574-579, Sciendirect, 2011.

[61] Harpreet Singh, Madan M. Gupta, Thomas Meitzler, Zeng-Guang Hou, Kum Kum Garg, Ashu M. G. Solo, and Lotfi A. Zadeh, "Real-Life Applications of Fuzzy Logic", Journal of Advances in Fuzzy Systems, Article ID 581879, 2013. DOI: http://dx.doi.org/10.1155/2013/581879

[62] Elmer P. Dadios, "Fuzzy Logic – Controls, Concepts, Theories and Applications", ISBN: 978-953-51-0396-7, 2012. DOI: 10.5772/2662

[63] **Nguyen Van Dong Hai**, Nguyen Thien Van, Nguyen Minh Tam, "Application of Fuzzy and PID Algorithm in Gantry Crane Control", Journal of Technical Education Science, ISSN: 1859-127, No. 44A, pp. 48-53, November, 2017.

[64] Sandeep D. Hanwate, Yogesh V. Hote, "Design of PID controller for IP using stability boundary locus", Annual Indian Conference (INDICON), IEEE, Indian, 2014.

[65] Mahadi Hasan, Chanchai Saha, Md. Mostafizur, Md. Rabiual Islam Sarker and Subrata K. Aditya, "Balancing of an IP using PD Controller", Journal of Science, Dhaka University, 60(1), pp. 115-120, 2012.

[66] C. Sravan Bharadwaj, T. Sudhakar Babu, N. Rajasekar, "Tuning PID Controller for IP using Genetic Algorithm", Advances in Systems, Control and Automation, Part of the Lecture Notes in Electrical Engineering, pp. 395-404, Springer, Dec-2017.

[67] Vishwa Nath, R. Mitra, "Swing-up and Control of Rotary IP using pole-placement with integrator", Recent Advances in Engineering and Computational Sciences (RAECS), 2014.

[68] Yan Lan, Minrui Fei, "Design of state-feedback controller by pole placement for a couple set of IPs", 10th International Conference on Electronics Measurement & Instruments (ICEMI), pp. 69-73, 2011.

[69] L. A. Zadeh, "Fuzzy sets", Journal of Information and Control, Vol. 8, Issues 3, pp. 338353, Elsevier, 1965.

[70] Sarah Spurgeon, "SMC: a tutorial", European Control Conference (ECC), pp. 2272-2277, IEEE, France, June-2104.

[71] **Nguyen Van Dong Hai**, Nguyen Minh Tam, Mircea Ivanescu, "A Method of Sliding Mode Control of Cart and Pole system", Journal of Science and Technology Development, ISSN: 1859-0128, Vol. 18, Nr. 6, pp. 167-173, Vietnam, 2015.

[72] Mircea Ivanescu, **Nguyen Van Dong Hai,** Nirvana Popescu, "Control algorithm for a class of systems described by TS-fuzzy uncertain models", 20th International Conference on System Theory, Control and Computing (ICSTCC), 2016. (ISI proceeding)

DOI:10.1109/ICSTCC.2016.7790653

[73] Sanket Kailas Gorade, Prasanna S. Gandhi, Shailaja R. Kurode, "Modeling and Output Feedback Control of Flexible IP on Cart", International Conference in Power and Advanced Control Engineering (ICPACE), pp. 436-440, IEEE, 2015.

[74] Chao Xu, Xin Yu, "Mathematical modeling of Elastic Inverted Pendulum control system", Journal of Control Theory and Applications, Vol. 2, Issue 3, pp. 281-282, Springer, 2004.

[75] Tang Jiali, Ren Gexue, "Modeling and Simulation of a Flexible IP System", Journal of Tsinghua Science and Technology, vol. 14, Nr. 82, pp. 22-26, 2009.

[76] Massachusetts Institute of Technology: "Laboratory Module. No. 1: Elastic behavior in Tension, bending, buckling, and vibration", Spring, 2004.

[77] **Nguyen Van Dong Hai,** Mircea Ivanescu, Mircea Nitulescu, "Observer-based Controller for Balancing Robot with Uncertain Model", 17th International Carpathian Control Conference (ICCC), pp226-231, IEEE, May-2016. (ISI proceeding)

[78] **Nguyen Van Dong Hai,** Mircea Ivanescu, Mihaela Florescu, Mircea Nitulescu, "Frequency criterion for balancing robot control described by uncertain models", 20th International Conference on System Theory, Control and Computing (ICSTCC), pp. 134-137, IEEE, October-2016. (ISI proceeding)

[79] Mircea Ivanescu, **Nguyen Van Dong Hai**, Nirvana Popescu, "Control Algorithm for a Calss of Systems Described by T-S Fuzzy Uncertain Models", pp. 129-133, IEEE, 2016. (ISI proceeding)

[80] Yasemin Ozkan Aydin, "Optimal Control of a Half Circular Compliant Legged Monopod", Doctor thesis. Middle East Technical University, 2013.

[81] Nguyen Xuan Vu Trien, Le Thi Thanh Hoang, Nguyen Minh Tam, **Nguyen Van Dong Hai,** "Feedback Control Design for a Walking Athlete Robot", Journal of Robotica & Management, ISSN: 1453-2069, Vol. 22, Nr. 1, June, 2017.

[82] Ege Sayginer, "Modelling the Effects of Half Circular Compliant Legs on the Kinematics and Dynamics of a Legged Robot", Master Thesis, Middle East University, 2010.

[83] R. M. Murray, "CDS 110b, Lecture 2- LQR", California Institute of Technology, 2006. Link: https://www.cds.caltech.edu/~murray/courses/cds110/wi06/lqr.pdf

[84] **Nguyen Van Dong Hai**, Mircea Ivanescu, Mircea Nitulescu, "Controller based on Lyapunov for a Class of Running Robot", 18th International Conference on Carpathian Control Conference (ICCC), pp. 107-111, July-2017.

[85] Christian Paulsson, "Dasher the running robot", Master thesis in electronics, control theory, 30p D-level, Malardalen University. Link: http://www.idt.mdh.se/utbildning/exjobb/files/TR1021.pdf

[86] Link: https://spectrum.ieee.org/automaton/robotics/humanoids/athlete-robot-learning-to-run-like-human

[87] Link: http://www.control.toronto.edu/people/profs/bortoff/acrobot.html

[88] Link: http://www.idc-online.com/technical_references/pdfs/mechanical_engineering/Energy_Methods.pdf

[89] Link: https://eis.hu.edu.jo/ACUploads/10526/CH%204.pdf

[90] Scott C. Brown, Kevin M. Passino, "Intelligent Control of an Acrobot", Journal of Intelligent and Robotic Systems, Vol. 18, Issue 3, pp. 209-248, 1997.

[91] Jiri Zikmund, Sergej Celikovsky, Claude H. Moog, "Nonlinear Control Design for the Acrobot", IFAC Proceedings Volumes, Volume 40, Issue 20, pp. 446-451, 2007.

[92] Ancai Zhang, Jinhua She, Xuzhi Lai, Min Wu, "Motion planning and tracking control for an acrobot based on a rewinding approach", Journal Automatica (Journal of IFAC), Vol. 49, Issue 1, pp. 278-284, 2013.

[93] Ikuo Mizuuchi, Yuto Nakanishi, Yoshinao Sodeyama, Yuta Namiki, Tamaki Nishino, Naoya Muramatsu, Junichi Urata, Kazuo Hongo, Tomoaki Yoshikai, and Masayuki Inaba, "An advanced musculoskeletal humanoid kojiro", In *Proc.* 7th IEEE-RAS Int. Conf. on Humanoid Robots (Humanoids 2007), pp 294–299, November 2007.

[94] R.Niiyama, S.Nishikava, Y.Kuniyoshi, "Athlete Robot with Applied Human Muscle Activation Pattern for Bipedal Running Robot", In Proc. IEEE/RSJ Int.Conf. on Intelligent Robots and Systems (IROS 2009), pp 1092–1099, October 10–15, 2009.

[95] Y.Gangamwar, V.Deo, S.Chate, M.Bahandare, H.Desphande, "Determination of Curved Beam Deflection by Using Castigliano's Theorem", Int Journal for Research in Emerging Science and Technology, Vol 3, Issue 5, , pp 19-24, 2016.

[96] R.Cardozzo, M.Mezza, "Comparison of Two Fuzzy Skyhook Control Strategies Applied to an Active Suspension", Int. Journal of Computer Science and Software Engineering, Vol 5, Issue 6,pp 108-113, 2016

[97] H.Vasudevan, A.Dollar, J.Morell, Design for Control of Wheeled Inverted Pendulum Platforms, Journal of Mechanisms and Robotics, ASME 2015, Vol. 7 / 041005-1

[98] Khalil, N. H., 2002, Nonlinear Systems, Prentice Hall, Upper Saddle River, NJ.

[99] Marc H. Raibert., "Legged Robots That Balance", The MIT Press, 1986.

[100] Ryosuke Tajima, Daisaku Honda, and Keisuke Suga, “Fast running experiments involving a humanoid robot”, In Proc. IEEE Int. Conf. On Robotics and Automation (ICRA2009*)*, pp 1571–1576, May 2009.

[101] Toru Takenaka, Takashi Matsumoto, TakahideYoshiike, and Shinya Shirokura. “Real time motion generation and control for biped robot —2nd report: Running gait pattern generation”, In Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS 2009), pp 1092–1099, October 10–15, 2009.

[102] R. McNeill Alexander and H. C. Bennet-Clark, “Storage of elastic strain energy in muscle and other tissues”, *Nature*, 265(5590):114–117, Jan 1977.

[103] Sang-Ho Hyon, “Compliant terrain adaptation for biped humanoids without measuring ground surface and contact forces”, IEEE Transactions on Robotics, 25(1):171–178, Feb. 2009.

[104] Hong Jie-Ren, “Balance Control of a Car-Pole Inverted Pendulum System”, Master theiss, National University of ChengKung, Taiwan, 2002.

[105] Ashwani Kharola and Pavin Patil, “Fuzzy Hybrid Control of Flexible Inverted Pendulum (FIP) System using Soft-computing Techniques”, Pertanika Journal of Science and Technology, 25(4), pp. 1189-1202, 2017.

[106] Yawei Peng, Jinkun Liu, Wei He, “Boundary Control for a Flexible Inverted Pendulum System based on a PDE Model”, Asian Journal of Control, Vol. 20, Issue 1, 2016.

[107] Altendorfer, R., Moore, N., Komsuoglu, H. et al, “RHex: A Biologically Inspired Hexapod Runner” Autonomous Robots (2001) 11: 207.

LIST OF PUBLICATIONS

International Journal

1. Huynh Xuan Dung, Huynh Duong Khanh Linh, Vu Dinh Dat, Nguyen Thanh Phuong, Nguyen Minh Tam, **Nguyen Van Dong Hai**, “Application of Fuzzy Algorithm in Optimizing Hierarchical Sliding Mode Control for Pendubot System”, International Journal of Robotica & Management, ISSN-L: 1453-2069; Print ISSN: 1453-2069; Online ISSN: 2359-9855 ,Vol. 22, Nr. 2, Dec-2017.
2. Nguyen Minh Hoang, Ngo Van Thuyen, Nguyen Minh Tam, Le Thi Thanh Hoang, **Nguyen Van Dong Hai**, “Desiging Linear Feedback Controller for Elastic IP with Tip Mass”, International Journal of Robotica & Management, ISSN-L: 1453-2069; Print ISSN: 1453-2069; Online ISSN: 2359-9855 , pp. 27-32, Vol. 21, Nr. 2, December-2016.
3. **Nguyen Van Dong Hai**, Huynh Xuan Dung, Nguyen Minh Tam, Cristian Vladu, Mircea Ivanescu, “Hierarchical Sliding Mode Algorithm for Athlete Robot Walking”, Journal of Robotics, ISSN: 1687-9600 (Print), ISSN: 1687-9619 (Online), Article ID

6348980, Hindawi, December-2017. DOI: doi.org/10.1155/2017/6348980 (ISI/ESCI/SCOPUS journal).
Link: https://www.hindawi.com/journals/jr/2017/6348980/

4. Nguyen Xuan Vu Trien, Le Thi Thanh Hoang, Nguyen Minh Tam, **Nguyen Van Dong Hai,** "Feedback Control Design for a Walking Athlete Robot", Journal of Robotica & Management, ISSN-L: 1453-2069; Print ISSN: 1453-2069; Online ISSN: 2359-9855, Vol. 22, Nr. 1, June, 2017.

5. Mihaela Florescu, **Van Dong Hai Nguyen**, Mircea Ivanescu, "Output Track Controller with Gravitational for a Class of Hyper-Redundant Robot Arms", Journal of Studies in Informatics and Control, Romania, 2015 (ISI/SCIE journal)
Link: https://sic.ici.ro/output-track-controller-with-gravitational-compensation-for-a-class-of-hyper-redundant-robot-arms/

International Conference

1. **Nguyen Van Dong Hai,** Mircea Ivanescu, Mircea Nitulescu, "Hierarchical Sliding Mode Control for Balancing Athlete Robot", 21st International Conference on System Theory, Control and Computing (ICSTCC 2017), Sinaia, Romania, Nov-2017.

2. **Nguyen Van Dong Hai**, Nguyen Minh Tam, Mircea Ivanescu, "Application in Genetic Algorithm in Identifying System Parameters for IP", International Sysmposium of Electrical and Electronics Engineering, Ho Chi Minh city University of Technology, Vietnam October-2015.

3. Mircea Ivanescu, **Nguyen Van Dong Hai,** Nirvana Popescu, "Control algorithm for a class of systems described by TS-fuzzy unvertain models", 20th International Conference on System Theory, Control and Computing (ICSTCC), 2016. (ISI proceeding). DOI:10.1109/ICSTCC.2016.7790653

4. M. Nitulescu, M. Ivanescu, S. Manoiu-Olaru, **Nguyen V. D. H**, *Experiment Platform for Hexapod Locomotion*, Book of Mechanisms and Machine Science, Vol. 46, Part VIII: Robotics-Mobile Robots, pp. 241-249, Springer, 2017. DOI: 10.1007/978-3-319-45450-4.

5. M. Ivanescu, M. Nitulescu, **Nguyen V. D. H**, M. Florescu, *Dynamic Control for a Class of Continuum Robotics Arms*, Book of Mechanisms and Machine Science, Vol. 46, Part XI: Robotics-Robotic Control System, pp. 361-370, Springer, 2017. DOI: 10.1007/978-3-319-45450-4.

6. **Nguyen Van Dong Hai,** Mircea Ivanescu, Mircea Nitulescu, "Observer-based Controller for Balancing Robot with Uncertain Model", 17th International Carpathian Control Conference (ICCC), pp226-231, IEEE, May-2016. (ISI proceeding)

7. **Nguyen Van Dong Hai,** Mircea Ivanescu, Mihaela Florescu, Mircea Nitulescu, "Frequency criterion for balancing robot control described by uncertain models", 20th International Conference on System Theory, Control and Computing (ICSTCC), pp. 134-137, IEEE, October-2016. (ISI proceeding)

8. Mircea Ivanescu, **Nguyen Van Dong Hai**, Nirvana Popescu, "Control Algorithm for a Calss of Systems Described by T-S Fuzzy Uncertain Models", pp. 129-133, IEEE, 2016. (ISI proceeding)
9. **Nguyen Van Dong Hai**, Mircea Ivanescu, Mircea Nitulescu, "Controller based on Lyapunov for a Class of Running Robot", 18th International Conference on Carpathian Control Conference (ICCC), pp. 107-111, July-2017.

Vietnamese domestic paper

1. **Nguyen Van Dong Hai,** Nguyen Phong Luu, Nguyen Minh Tam, Hoang Ngoc Van, "Optimal Control for Quadruped IP", pp. 18-23, Vol. 34, Journal of Technical Education Science, Vietnam, ISSN: 1859-1272, 2016.
2. Tran Hoang Chinh, Nguyen Minh Tam, **Nguyen Van Dong Hai,** "A Method of PID-FUZZY control for pendubot", Journal of Technical Education Science, No. 44A, pp. 61-67, ISSN: 1859-127, November-2017.
3. Nguyen Minh Tam, **Nguyen Van Dong Hai**, Nguyen Phong Luu, Le Van Tuan, "Modelling and Optimal Control for Two-wheeled Self-Balancing Robot", Journal of Technical Education Science, Vietnam, ISSN: 1859-1272, Vol. 37, pp. 35-41, 2016.
4. Ho Trong Nguyen, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "Application of Genetic Algorithm in Optimization Controller for Cart and Pole System", Journal of Technical Education Science, ISSN: 1859-127, No. 44A, pp. 41-47, November, 2017.
5. Vu Duc Ha, Huynh Xuan Dung, Nguyen Minh Tam, **Nguyen Van Dong Hai**, "Hierarchical Fuzzy SMC for a Class of SIMO Under-actuated Systems", Journal of Technical Education Science, ISSN: 1859-1272, Vietnam, 2017.
6. Vu Dinh Dat, Huynh Xuan Dung, Phan Van Kiem, Nguyen Minh Tam, **Nguyen Van Dong Hai,** "A method of Fuzzy-SMC for Pendubot model", Journal of Science and Technology-University of Da Nang, Vietnam, ISSN: 1859-1591, No. 11 (120), Issue 1, pp. 12-16, 2017.
7. **Nguyen Van Dong Hai**, Nguyen Thien Van, Nguyen Minh Tam, "Application of Fuzzy and PID Algorithm in Gantry Crane Control", Journal of Technical Education Science, ISSN: 1859-127, No. 44A, pp. 48-53, November, 2017.
8. **Nguyen Van Dong Hai,** Nguyen Minh Tam, Mircea Ivanescu, "A Method of Sliding Mode Control of Cart and Pole system", Journal of Science and Technology Development, ISSN: 1859-0128, Vol. 18, Nr. 6, pp. 167-173, Vietnam, 2015.
9. Vo Anh Khoa, Nguyen Minh Tam, Le Thi Thanh Hoang, Nguyen Thien Van, **Nguyen Van Dong Hai**, "Model and Control Algorithm Construction for Rotary Inverted Pendulum in Laboratory", Journal of Technical Education Science, ISSN: 18959-1272, 2018. (in Vietnamese) (accepted)
10. Vo Anh Khoa, Nguyen Minh Tam, Le Thi Thanh Hoang, Nguyen Thien Van, Mircea Ivanescu, **Nguyen Van Dong Hai,** "PID controller in Step-motion Control for Bipedal

Robot with Elastic Legs", Journal of Technical Education Science, ISSN: 1859-127, 2018. (accepted)