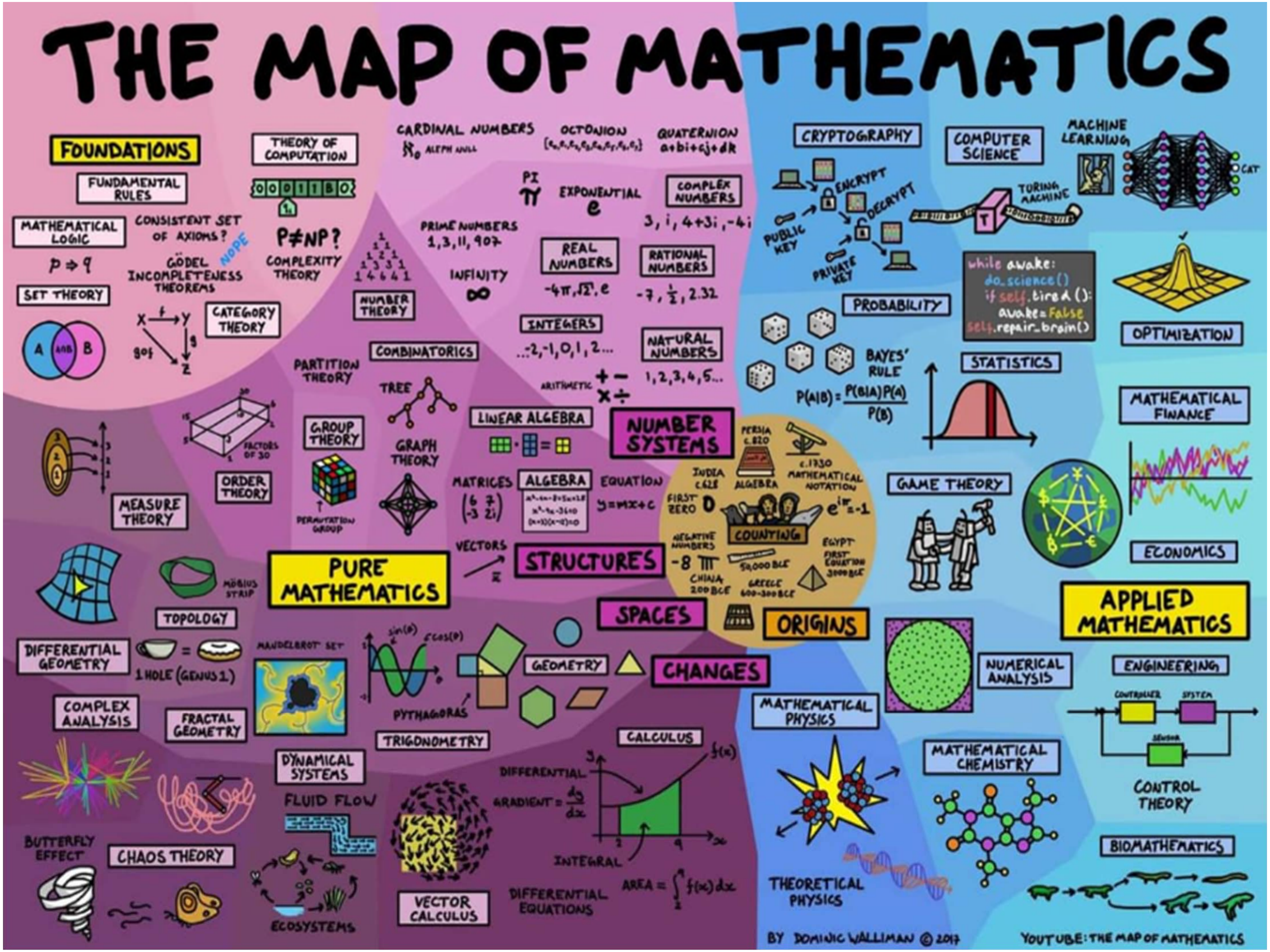
Model-free Neuromuscular Electrical Stimulation by Stochastic Extremum Seeking

Prof. Tiago Roux Oliveira

Rio de Janeiro, 23 de Maio de 2019

OUTLINE


THE MAP OF MATHEMATICS
FOUNDATIONS
THEORY OF COMPUTATION
FUNDAMENTAL RULES
MATHEMATICAL LOGIC
CONSISTENT SET OF AXIOMS?
NOPE
GÖDEL INCOMPLETENESS THEOREMS
P≠NP?
COMPLEXITY THEORY
SET THEORY
CATEGORY THEORY
CARDINAL NUMBERS
ALEPH NULL
OCTONION
QUATERNION
a+bi+cj+dk
PI
EXPONENTIAL
COMPLEX NUMBERS
3, i, 4+3i, -4i
PRIME NUMBERS
1,3,11,907
REAL NUMBERS
RATIONAL NUMBERS
INFINITY
NUMBER THEORY
INTEGERS
..-2,-1,0,1,2...
NATURAL NUMBERS
1,2,3,4,5...
ARITHMETIC
COMBINATORICS
PARTITION THEORY
TREE
LINEAR ALGEBRA
NUMBER SYSTEMS
FACTORS OF 30
MEASURE THEORY
ORDER THEORY
GROUP THEORY
GRAPH THEORY
PERMUTATION GROUP
MATRICES
ALGEBRA
EQUATION
y=mx+c
VECTORS
STRUCTURES
PURE MATHEMATICS
MÖBIUS STRIP
TOPOLOGY
SPACES
ORIGINS
COUNTING
DIFFERENTIAL GEOMETRY
1 HOLE (GENUS 1)
MANDELBROT SET
GEOMETRY
CHANGES
PYTHAGORAS
COMPLEX ANALYSIS
FRACTAL GEOMETRY
TRIGONOMETRY
CALCULUS
DYNAMICAL SYSTEMS
DIFFERENTIAL
GRADIENT = dy/dx
FLUID FLOW
INTEGRAL
AREA = ∫ f(x) dx
BUTTERFLY EFFECT
CHAOS THEORY
ECOSYSTEMS
VECTOR CALCULUS
DIFFERENTIAL EQUATIONS
CRYPTOGRAPHY
ENCRYPT
DECRYPT
PUBLIC KEY
PRIVATE KEY
COMPUTER SCIENCE
MACHINE LEARNING
CAT
TURING MACHINE
while awake:
do_science()
if self.tired():
awake = False
self.repair_brain()
PROBABILITY
OPTIMIZATION
BAYES' RULE
P(A|B) = P(B|A)P(A) / P(B)
STATISTICS
MATHEMATICAL FINANCE
GAME THEORY
ECONOMICS
APPLIED MATHEMATICS
NUMERICAL ANALYSIS
ENGINEERING
MATHEMATICAL PHYSICS
MATHEMATICAL CHEMISTRY
CONTROL THEORY
THEORETICAL PHYSICS
BIOMATHEMATICS
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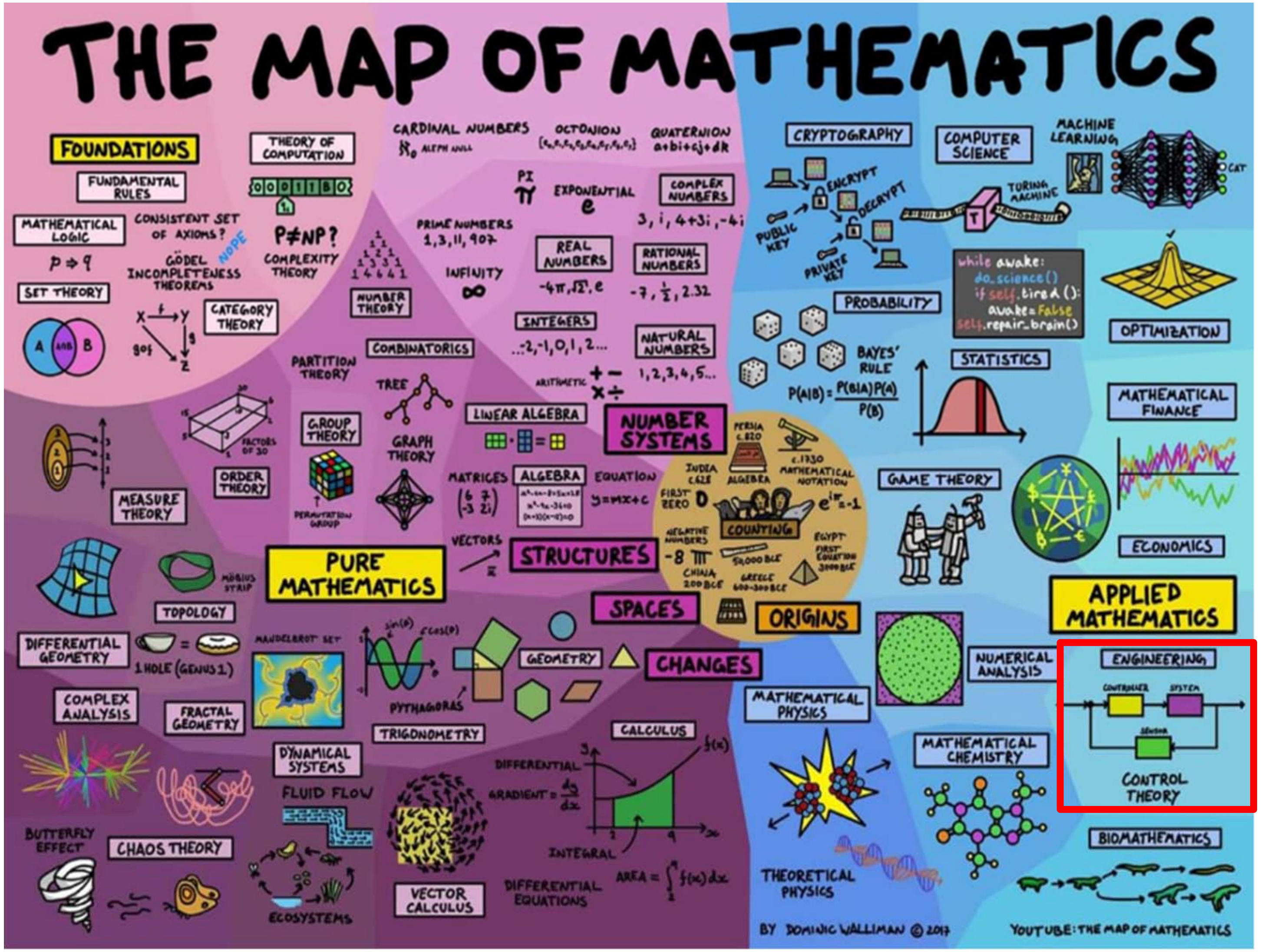
YOUTUBE: THE MAP OF MATHEMATICS



- ✓ NONLINEAR SYSTEMS
- ✓ ADAPTIVE CONTROL / EXTREMUM SEEKING
- ✓ SLIDING MODE CONTROL
- ✓ TIME DELAYS
- ✓ PDEs

CAREER ACHIEVEMENTS

EDUCATION

2006-2010 **Ph.D. in Electrical Engineering (Control Theory),** COPPE/UFRJ
Federal University of Rio de Janeiro, under the supervision of Prof. Liu Hsu

2004-2006 **M.Sc. in Electrical Engineering (Control Theory),** COPPE/UFRJ
Federal University of Rio de Janeiro, under the supervision of Prof. Liu Hsu

2004-2006 **B.Sc. in Electrical Engineering (Telecommunications),** UERJ
State University of Rio de Janeiro, under the supervision of Prof. Alexandre Assis

EMPLOYMENT AND SERVICES

2010 - ... **State University of Rio de Janeiro (UERJ), Brazil** - Associate Professor

2014-2015 **University of California - San Diego (UCSD), California, USA** - Visiting Scholar/Researcher, Cymer Center for Control Systems and Dynamics, under the supervision of Prof. Miroslav Krstic

2014 - ... **International Federation on Automatic Control (IFAC)** - Member of Technical Committee, Adaptive/Learning Systems (TC1.2) & Control Design (TC2.1)

2016 - ... **Technical Committee on Variable Structure & Sliding Mode Control (IEEE)** - Member Roster

2016 **International Journal of Adaptive Control and Signal Processing (Wiley)** - Guest Editor

2017 - ... **Journal The Franklin Institute (Elsevier)** - Associate Editor

2018 - ... **IEEE Latin America Transactions** - Associate Editor

2018 - ... **Brazilian Academy of Sciences (ABC), Brazil** - Affiliate Member

PUBLICATIONS: 45 journal papers, 91 Conference papers, 09 Book Chapters

FUNDING AGENCIES :

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPERJ Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

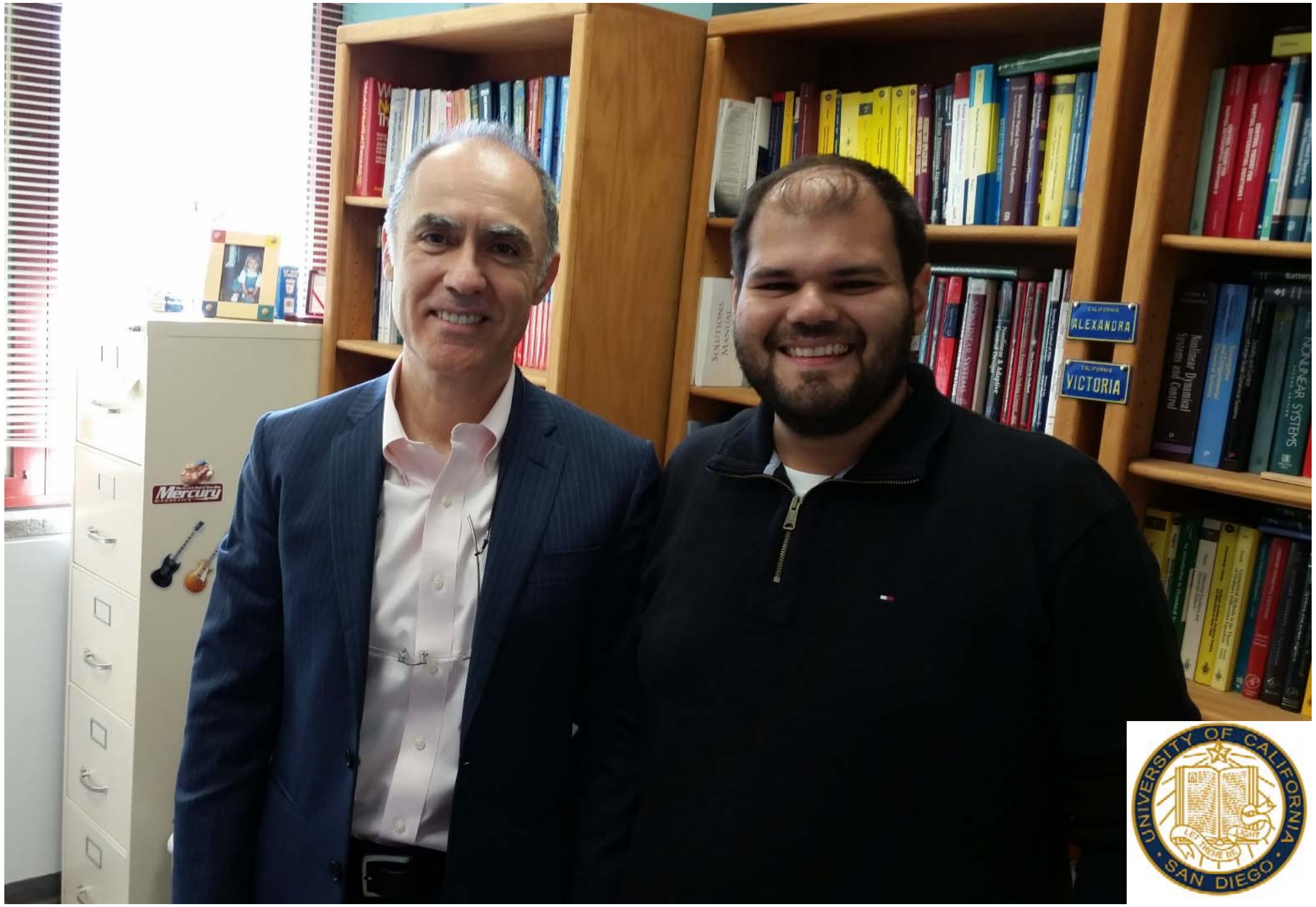
H-Factor Google Scholar: 14
Index i10 Google Scholar: 20

CAREER ACHIEVEMENTS

- **Prêmio CAPES de Teses 2011**

CAREER ACHIEVEMENTS

- **Pós-Doutorado: University of California (2014 - 2015)**



Prof. Miroslav Krstic

CAREER ACHIEVEMENTS

- **Membro Academia Brasileira de Ciências 2017 - 2021**

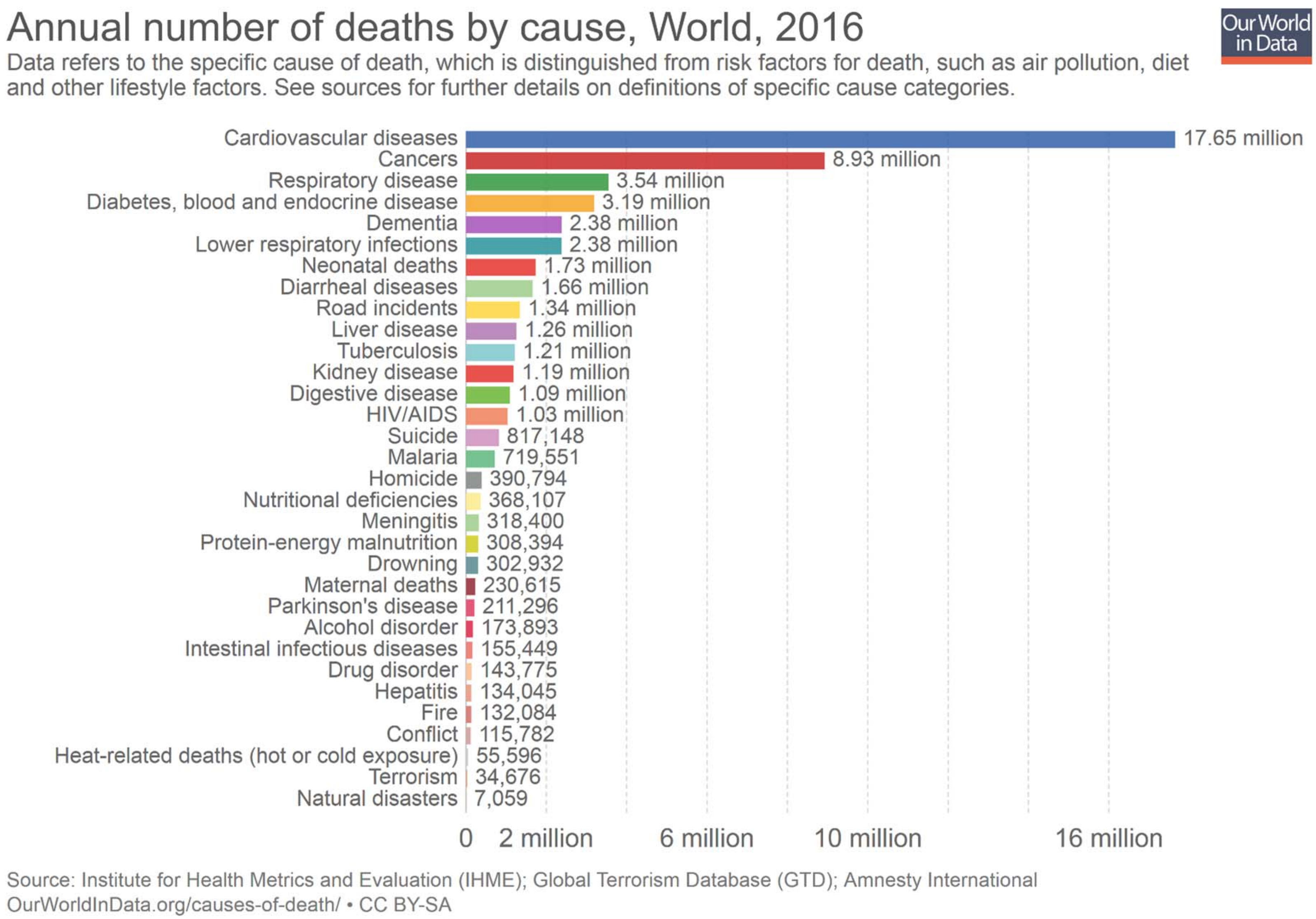
Prof. Liu Hsu

CAREER ACHIEVEMENTS

- **IEEE Senior Member (2018)**

MOTIVATION

STROKE DISEASE IN THE WORLD



MOTIVATION

Impact in social life / Depression

- ✓ motor disorder
- ✓ spasticity

Traditional Physioterapy

FES/NMES – AUTOMATED PHYSIOTHERAPY

APPLICATION TO FUNCTIONAL ELECTRICAL STIMULATION (FES)

Definition (Wikipedia):

FES is a technique that uses low energy electrical pulses to artificially generate body movements in individuals who have been paralyzed due to injury to the central nervous system. More specifically, FES can be used to generate muscle contraction in otherwise paralyzed limbs to produce functions such as grasping, walking, bladder voiding and standing ...

Human-in-the-loop!

(**NMES** – Neuromuscular Electrical Stimulation)

ASSISTIVE ROBOTICS FOR STROKE PATIENTS

– Motor disorder

– Spasticity (hypertonia)

– Physiotherapy

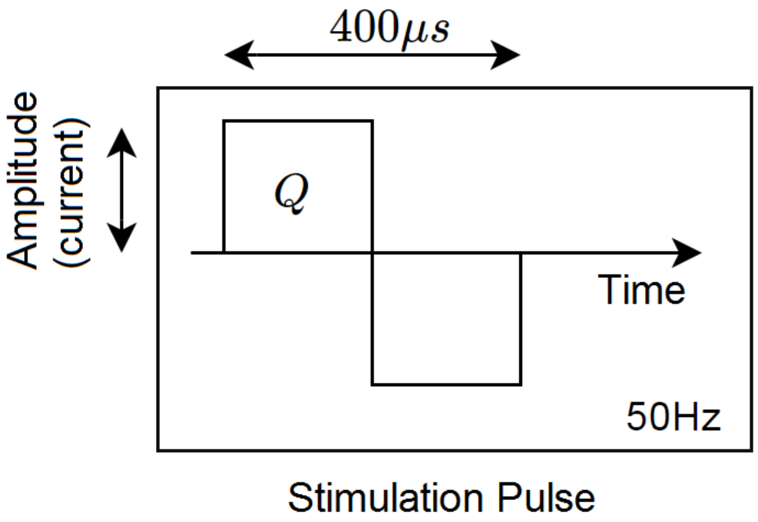
Rehabilitation

– Passive or active movement

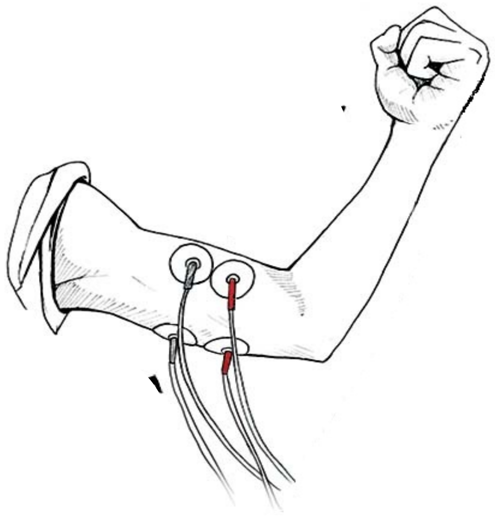
– Closed-loop feedback aids patients' recovery

– Design control laws for NMES

ELECTRODES AND ELECTRICAL SIGNAL



(Pulse Amplitude Modulation)



(Flexion and Extension

for Upper limbs)

MATERIALS AND METHODS

Instrumentation

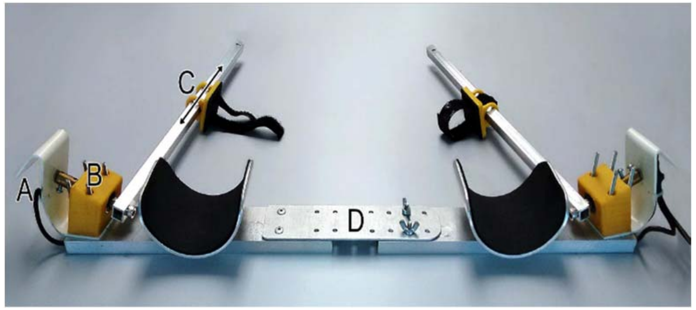
– Goniometer to obtain the elbow angle

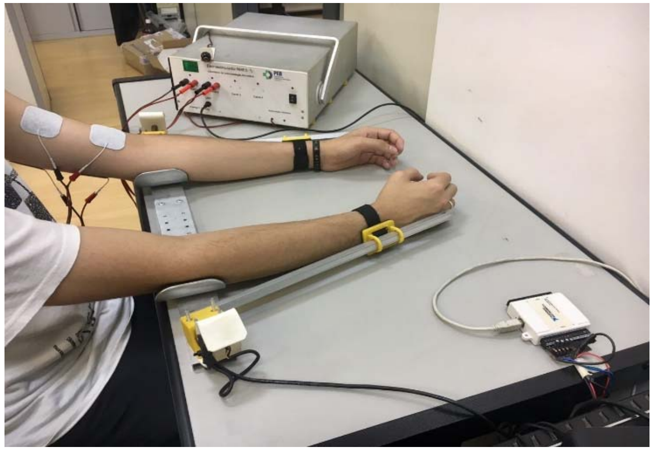
– Programmable NMES (to avoid discomfort to the patient)

– Interface and control code developed using LabVIEW 12.0

Mechanical Apparatus and Experimental Setup

– a single degree of freedom





MATERIALS AND METHODS

Volunteers

– Healthy volunteers

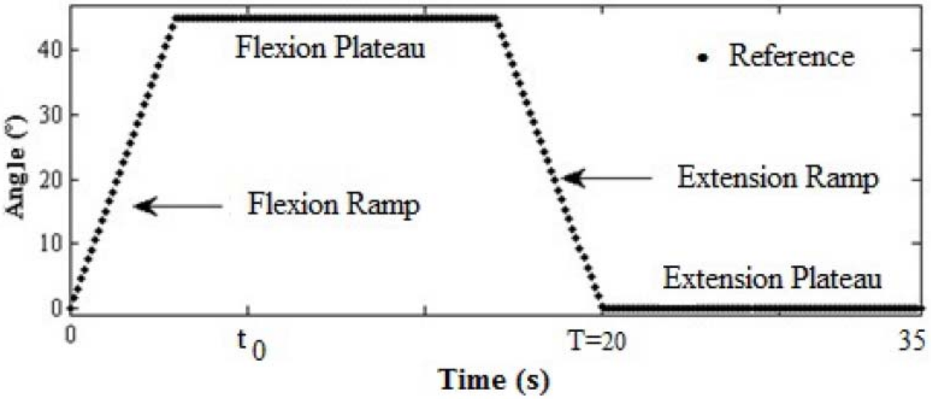
– Stroke Patients

– Focus on upper limbs

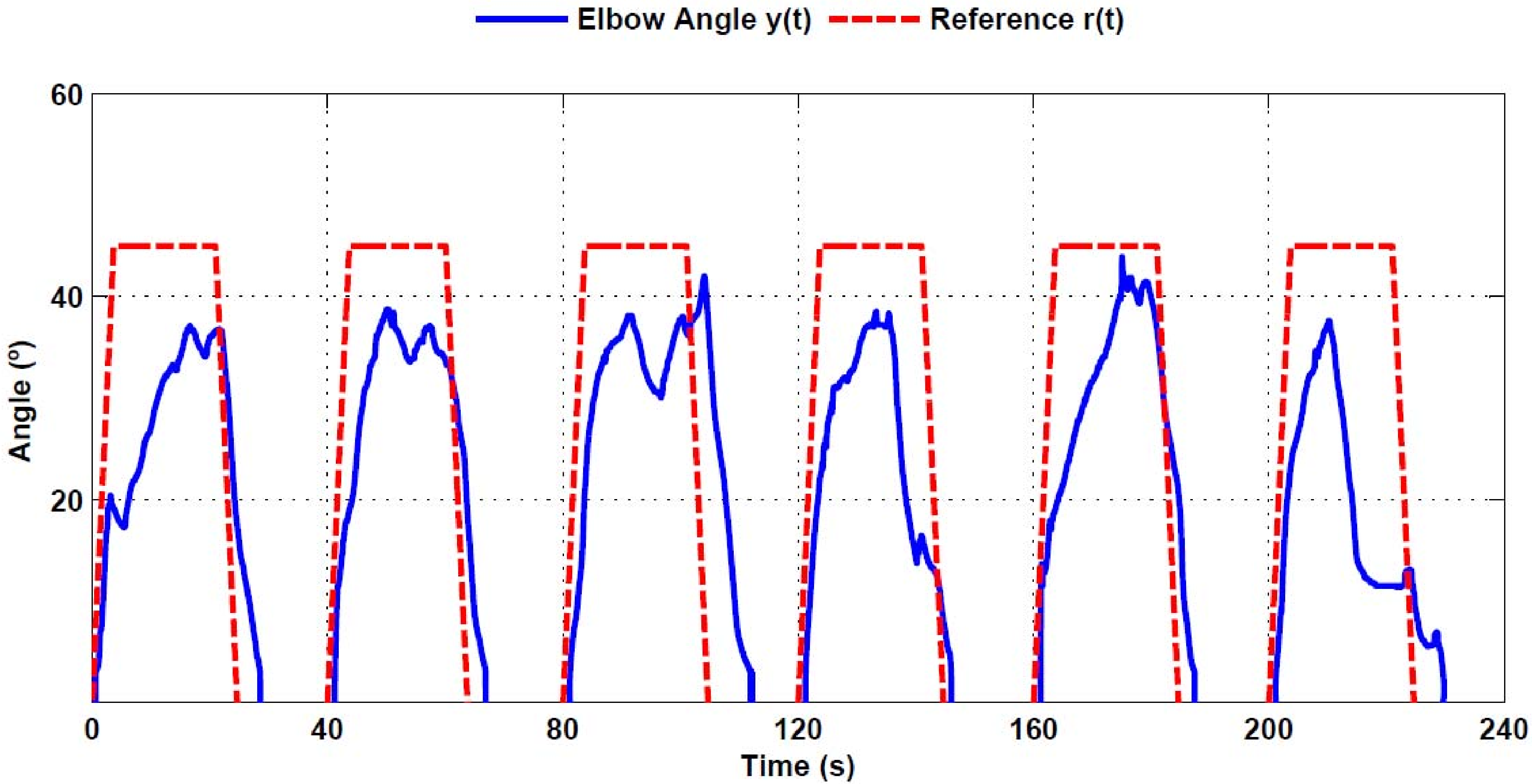
– Extension and flexion movements

– Four sets of movements up to 45º

(measured angle y)

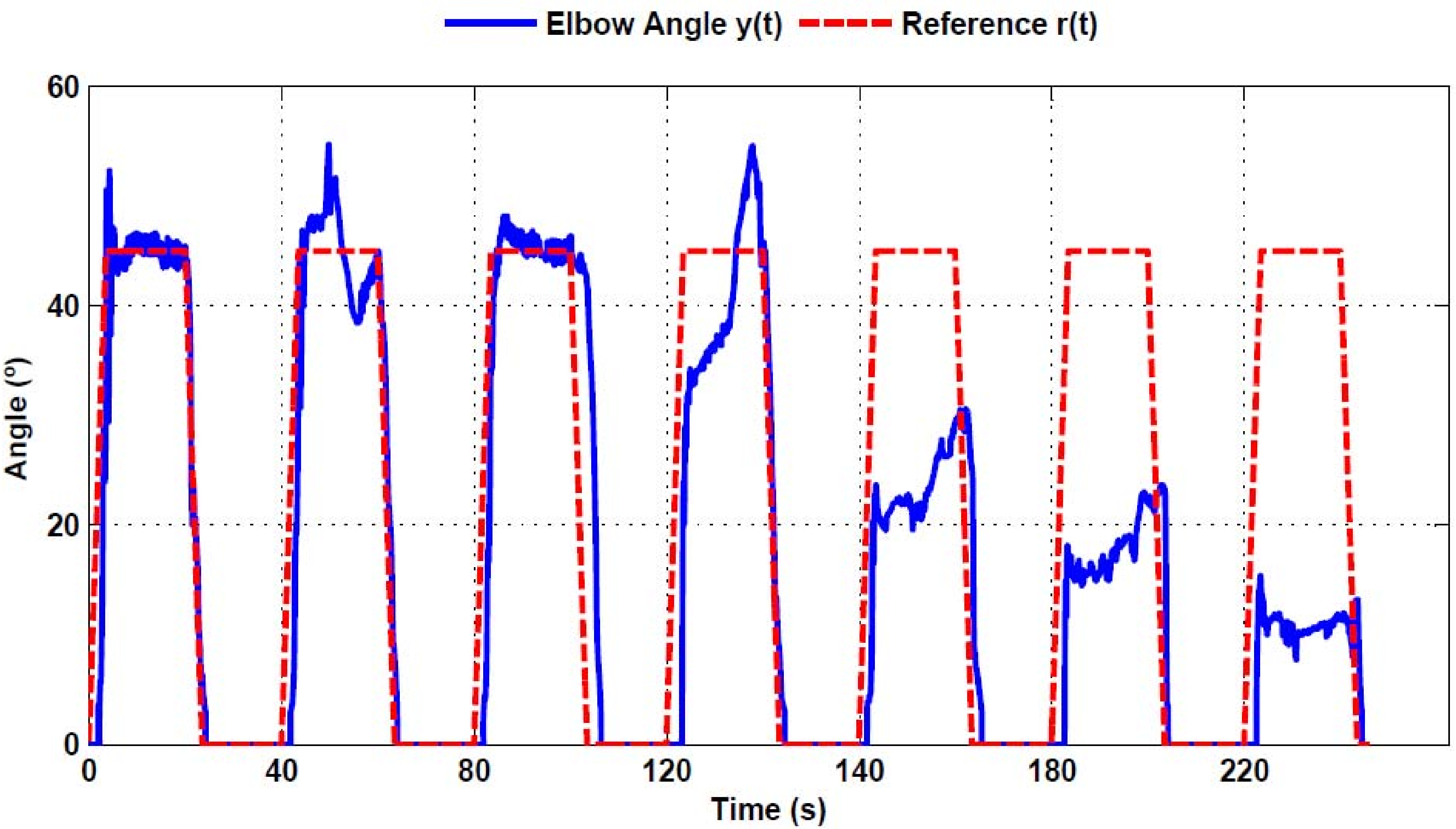


EXPERIMENTS WITH STROKE PATIENT WITHOUT STIMULATION

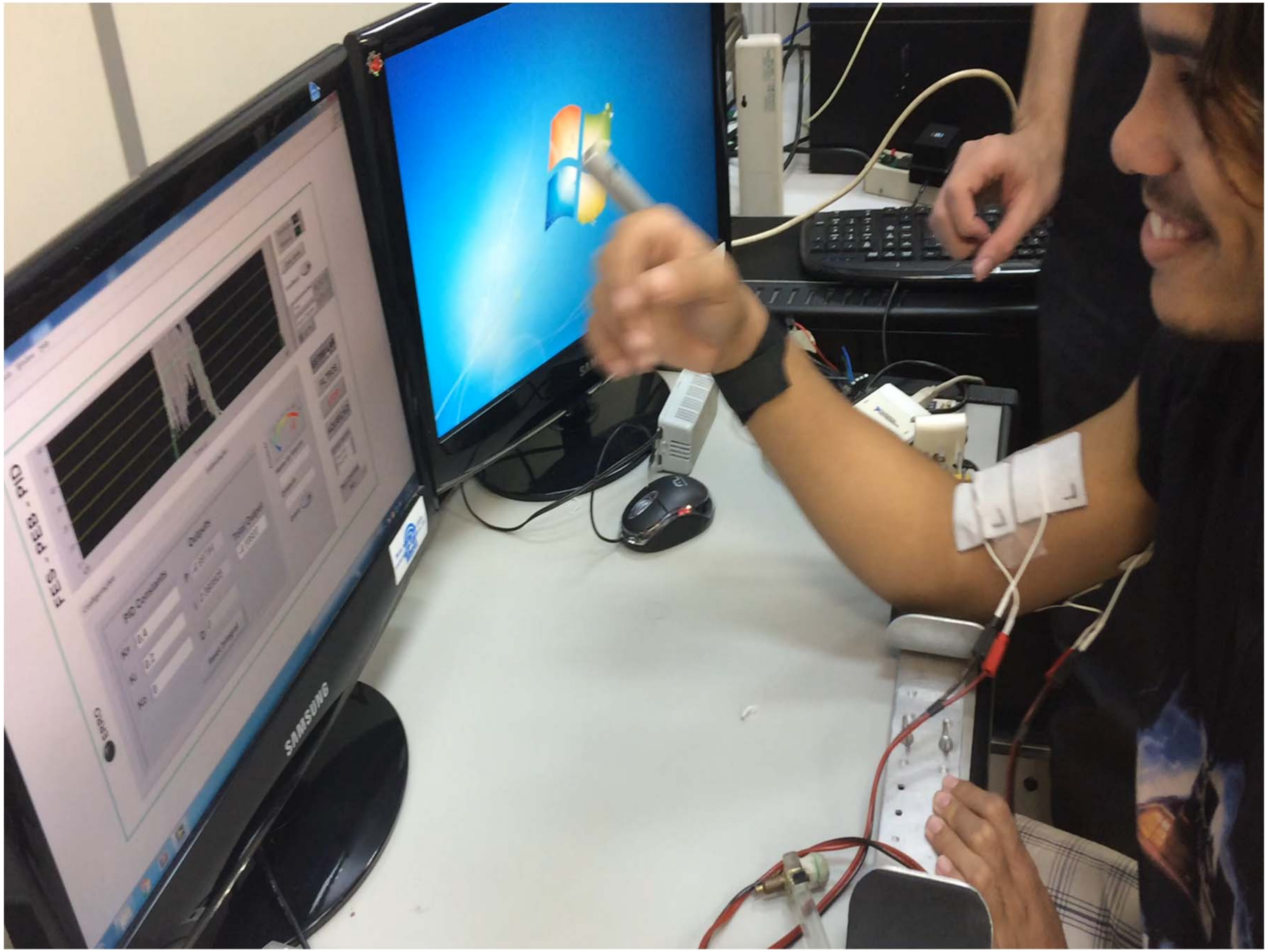


EXPERIMENTS WITH STROKE WITH PID CONTROLLER

PID WITH FIXED GAINS



FIXED GAINS – BAD TUNE



CHALLENGES FOR MODELING AND ACTUATION

– Different kinds of lesion (parametric/relative degree uncertainties)

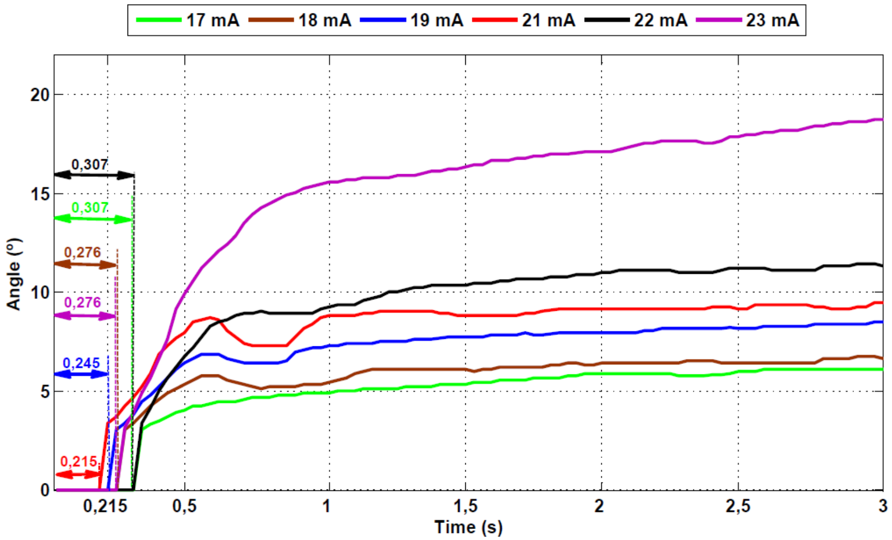
– Patient response changes over time (time-varying system)

– Saturation, dead-zone and fatigue (nonlinear phenomena)

– Gravity action (disturbances for upperward movements)

– Hybrid bidirectional actuator (biceps and triceps)

–Time delays (small but present)



CONTROL OBJECTIVES

- To apply Extremum Seeking algorithms to adapt the PID gains in order to achieve robustness for different patients

- Previous Works:

– Simple PI controller (demands a long process of tuning)

– Filtered Sliding Mode Control + Time-scaling technique (time dilation of the system responses, Padé approximations, singular perturbation theory)

– Combination of both...

PREVIOUS WORK WITH STROKE PATIENTS

ELSEVIER

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Time-scaling based sliding mode control for Neuromuscular Electrical Stimulation under uncertain relative degrees

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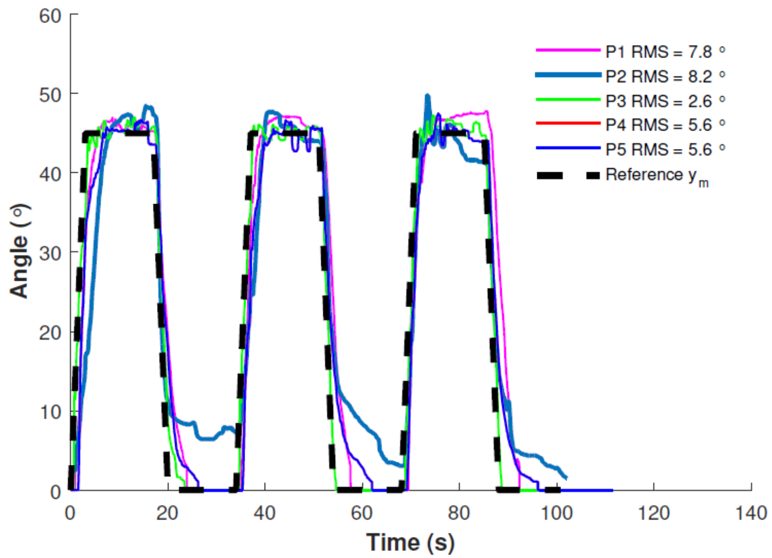
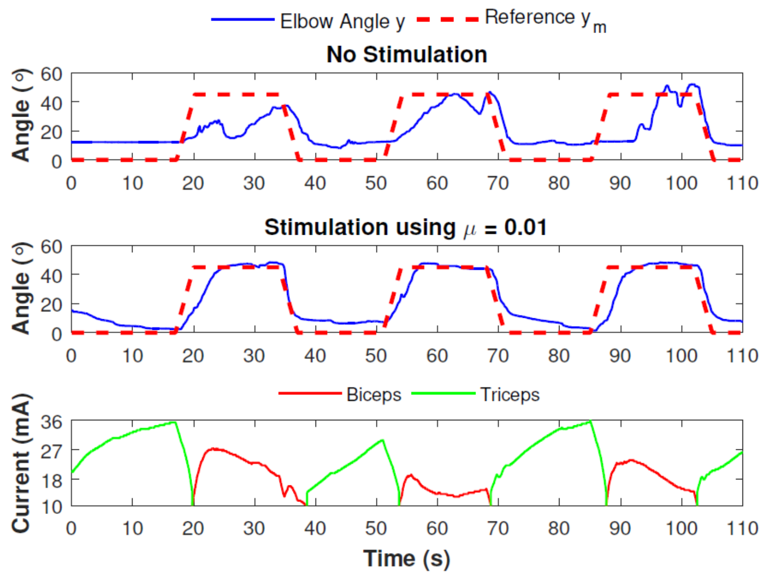
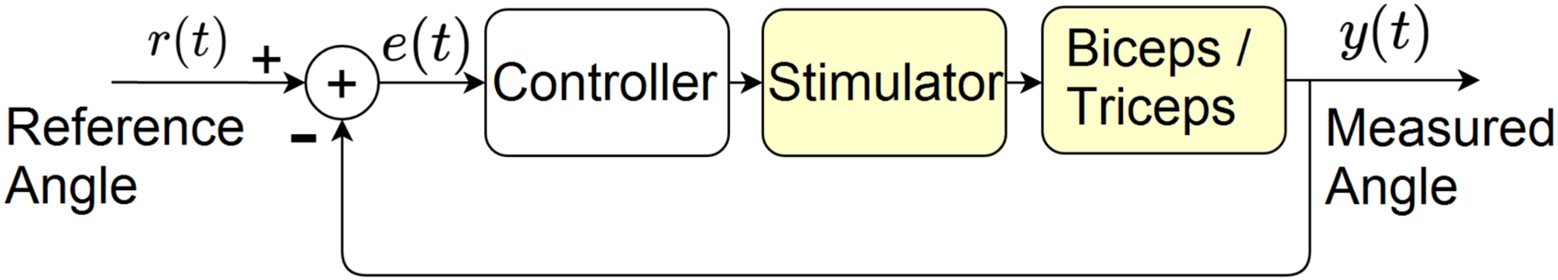
[a] Department of Electronics and Telecommunication Engineering, State University of Rio de Janeiro (UERJ), Rio de Janeiro, RJ 20550-900, Brazil
[b] Biomedical Engineering Program, Federal University of Rio de Janeiro (COPPE/UFRJ), P.O. Box 68510, Rio de Janeiro, RJ 21945-970, Brazil





ADAPTIVE CONTROL STRATEGY



Which Controller? Adaptive Control!

– Conventional Adaptive Control (control parametrization)

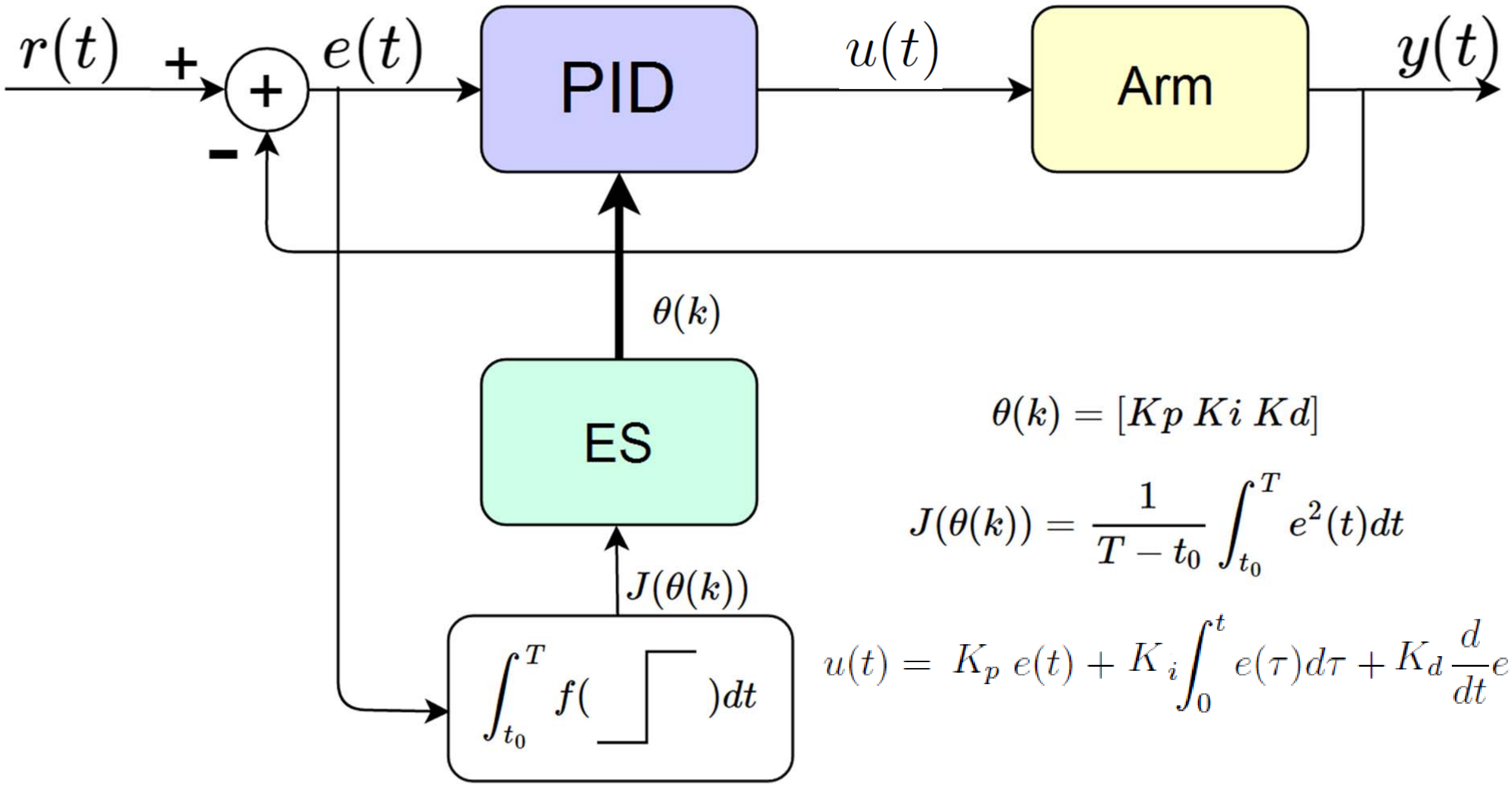
– Model Reference Adaptive Control (delays/relative degree obstacles)

– PID with Extremum Seeking for adaptation

Automatic controller tuning: adaptation

– May solve the huge gap between healthy volunteers and stroke patients

PROPOSED CONTROLLER (PID + ES)



$$\theta(k) = [Kp\ Ki\ Kd]$$

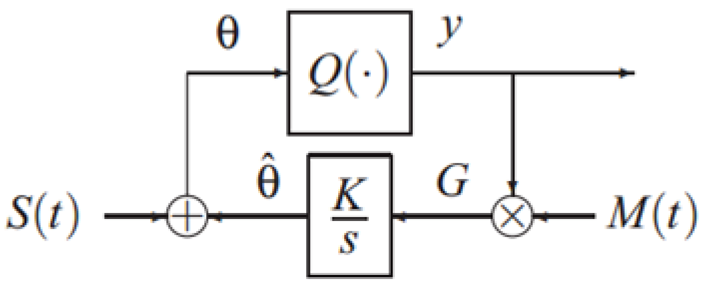
$$J(\theta(k)) = \frac{1}{T - t_0} \int_{t_0}^{T} e^2(t)dt$$

$$u(t) = K_p\, e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

BASICS OF DETERMINISTIC EXTREMUM SEEKING

Standard ES for Quadratic Map:

$$Q(\theta) = Q^* + \frac{H}{2}(\theta - \theta^*)^2$$



Hessian H > 0: Minimization
Hessian H < 0: Maximization

Dither Signals:

$$S(t) = a\sin(\omega t)$$
$$M(t) = \frac{2}{a}\sin(\omega t)$$

Averaging System:

$$\frac{d\tilde{\theta}_{\text{av}}(t)}{dt} = kH\tilde{\theta}_{\text{av}}(t)$$

(Hessian H > 0 and K < 0)

Estimation error $\tilde{\theta}(t) = \hat{\theta}(t) - \theta^*$ tends to $\mathcal{O}(a + 1/\omega)$

(by using Averaging Theorem)

BASICS OF DETERMINISTIC EXTREMUM SEEKING

SIMULATION

$$H = 2$$

$$Q^* = 0$$

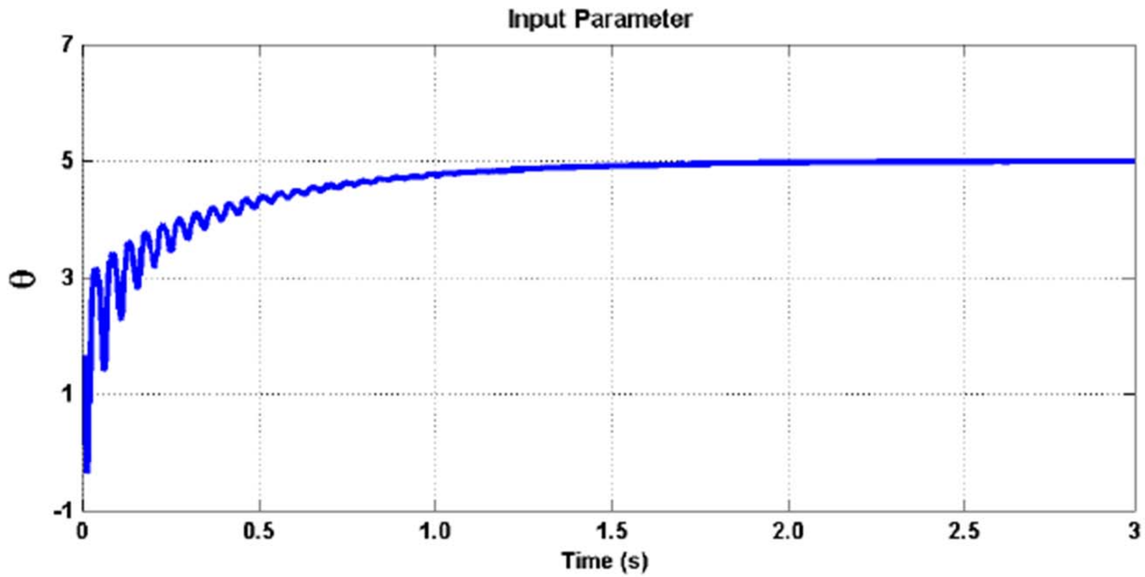
$$\theta^* = 5$$

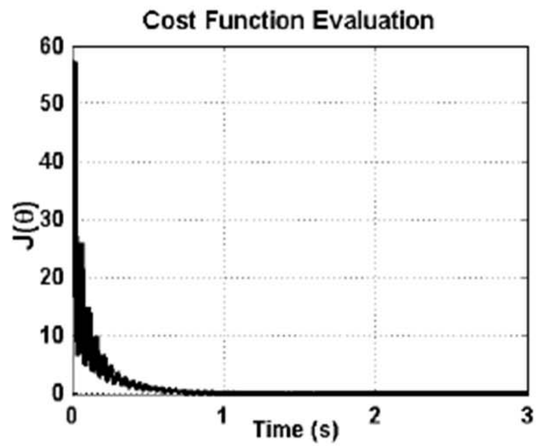
$$\hat{\theta}(0) = 2$$

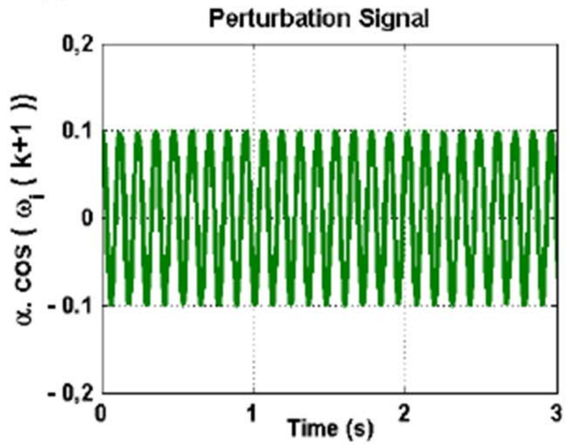
$$\omega = 2$$

$$\gamma = 0.01$$

$$a = 1$$







BASICS OF STOCHASTIC EXTREMUM SEEKING

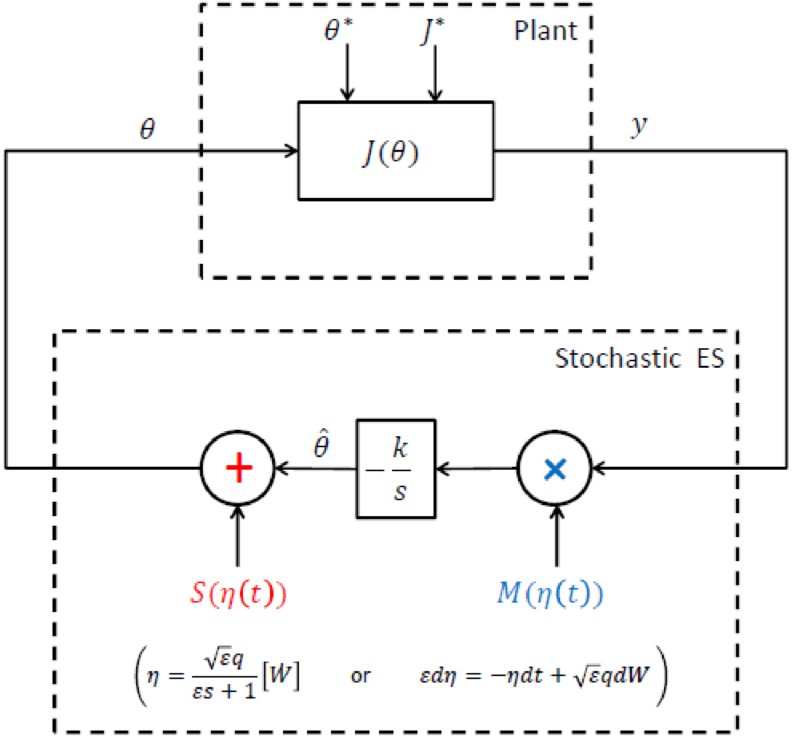
$$S(t) = a\eta t$$

$$M(t) = \frac{2}{a}\eta(t)$$

$$\tilde{\theta}(t) = \theta^* - \hat{\theta}(t)$$

$$\theta(t) = \hat{\theta}(t) + a\eta(t)$$

$$\theta(t) = a\eta(t) - \tilde{\theta}(t)$$



$$\dot{\tilde{\theta}}(t) = -\dot{\hat{\theta}}(t) = k\frac{2}{a}\eta(t)y(t) = k\frac{2}{a}\eta(t)f\big(\theta(t)\big)$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$S(t) = a\eta t$$

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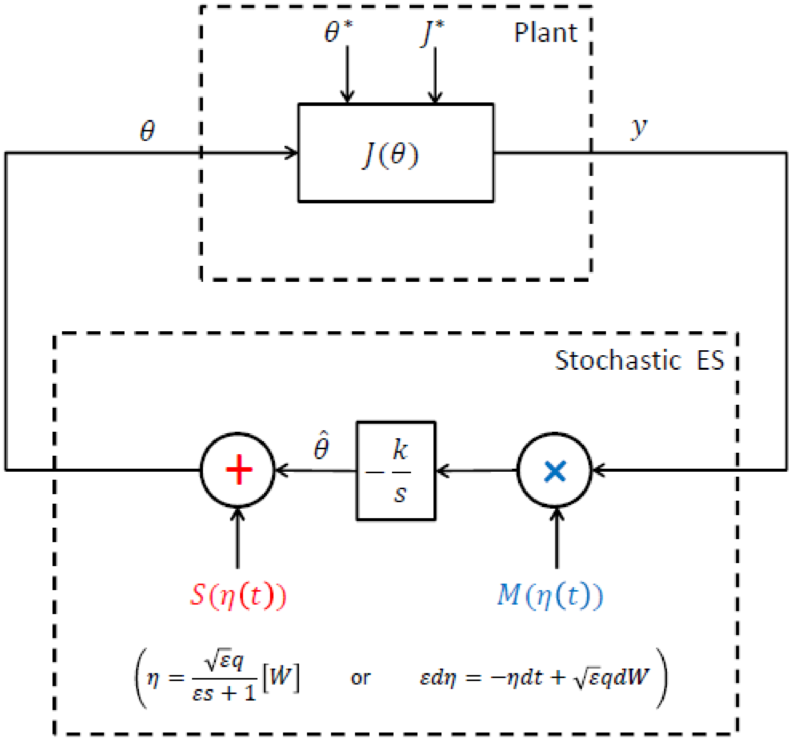


$$\dot{\tilde{\theta}}(t) = -\dot{\hat{\theta}}(t) = k\frac{2}{a}\eta(t)y(t) = k\frac{2}{a}\eta(t)f\big(\theta(t)\big)$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$\eta(t)$ ⟶ STOCHASTIC PERTURBATION

$$\varepsilon d\eta = -\eta dt + \sqrt{\varepsilon} q dW$$

$\dot{W}(t)$ *is a Gaussian white noise (with zero expectation and positive variance)*

If ε is sufficiently small $\rightarrow$ η *is a good approximation of the white noise*

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$f(\theta) = f\left(a\eta - \tilde{\theta}\right) \approx f(\theta^*) + f'(\theta^*)\left(a\eta - \tilde{\theta}\right) + \frac{1}{2}f''(\theta^*)\left(a\eta - \tilde{\theta}\right)^2$$

If $f(\theta)$ has a minimum at θ^* ⟶ $f'(\theta^*) = 0$

$$f(\theta) \approx f(\theta^*) + \underbrace{f'(\theta^*)\left(a\eta - \tilde{\theta}\right)}_{0} + \frac{1}{2}f''(\theta^*)\left(a\eta - \tilde{\theta}\right)^2$$

$$f(\theta) \approx f(\theta^*) + \frac{1}{2}f''(\theta^*)\left(a\eta - \tilde{\theta}\right)^2 = f(\theta^*) + \frac{1}{2}f''(\theta^*)\left(a^2\eta^2 - 2a\eta\tilde{\theta} + \tilde{\theta}^2\right)$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$\dot{\tilde{\theta}}(t) = k\frac{2}{a}\eta(t)f\big(\theta(t)\big)$$

$$f(\theta) \approx f(\theta^*) + \tfrac{1}{2}f''(\theta^*)\left(a^2\eta^2 - 2a\eta\tilde{\theta} + \tilde{\theta}^2\right)$$

$$\dot{\tilde{\theta}} \approx k\frac{2}{a}\eta\left\{f(\theta^*) + \frac{1}{2}f''(\theta^*)\left[a^2\eta^2 - 2a\eta\tilde{\theta} + \tilde{\theta}^2\right]\right\}$$

$$= k\frac{2}{a}\eta\left[f(\theta^*) + \frac{a^2}{2}f''(\theta^*)\eta^2 - af''(\theta^*)\eta\tilde{\theta} + \frac{1}{2}f''(\theta^*)\tilde{\theta}^2\right]$$

$$\dot{\tilde{\theta}}(t) = k\frac{2}{a}\eta(t)\left[f(\theta^*) + \frac{1}{2}f''(\theta^*)\tilde{\theta}^2(t)\right] - 2k\eta^2(t)f''(\theta^*)\tilde{\theta}(t) + k\eta^3(t)af''(\theta^*)$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$\dot{\tilde{\theta}}(t) = k\frac{2}{a}\eta(t)\left[f(\theta^*) + \frac{1}{2}f''(\theta^*)\tilde{\theta}^2(t)\right] - 2k\eta^2(t)f''(\theta^*)\tilde{\theta}(t) + k\eta^3(t)af''(\theta^*)$$

$$\lim_{t\longrightarrow+\infty} E\{\eta(t)\} = 0 \qquad \lim_{t\longrightarrow+\infty} E\{\eta^2(t)\} = \frac{q^2}{2} \qquad \lim_{t\longrightarrow+\infty} E\{\eta^3(t)\} = 0$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$\dot{\tilde{\theta}}(t) = k\frac{2}{a}\eta(t)\left[f(\theta^*) + \frac{1}{2}f''(\theta^*)\tilde{\theta}^2(t)\right] - 2k\eta^2(t)f''(\theta^*)\tilde{\theta}(t) + k\eta^3(t)af''(\theta^*)$$

$$\lim_{t\longrightarrow+\infty} E\{\eta(t)\} = 0 \qquad \lim_{t\longrightarrow+\infty} E\{\eta^2(t)\} = \frac{q^2}{2} \qquad \lim_{t\longrightarrow+\infty} E\{\eta^3(t)\} = 0$$

$$\dot{\tilde{\theta}}(t) = k\frac{2}{a}\underbrace{\eta(t)}_{\to 0}\left[f(\theta^*) + \frac{1}{2}f''(\theta^*)\tilde{\theta}^2(t)\right]\boxed{- 2k\eta^2(t)f''(\theta^*)\tilde{\theta}(t)} + k\underbrace{\eta^3(t)}_{\to 0}af''(\theta^*)$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

$$\lim_{t \to +\infty} E\{\eta(t)\} = 0 \qquad \lim_{t \to +\infty} E\{\eta^2(t)\} = \frac{q^2}{2} \qquad \lim_{t \to +\infty} E\{\eta^3(t)\} = 0$$

$$\varepsilon d\eta = -\eta dt + \sqrt{\varepsilon} q dW$$

Applying Ito's differentiation rule to η^2

we obtain the ordinary differential equation

$$\frac{\varepsilon}{2}\frac{dE\{\eta^2\}}{dt} = -E\{\eta^2\} + \frac{q^2}{2}$$

with solution being simply:

$$E\{\eta^2(t)\} = e^{-2t/\varepsilon} E\{\eta^2(0)\} + \frac{q^2}{2}\left(1 - e^{-2t/\varepsilon}\right) \;\Rightarrow\; \frac{q^2}{2} \text{ as } t \to \infty$$

$$\dot{\tilde{\theta}}(t) \approx -kq^2 f''(\theta^*)\tilde{\theta}(t) \qquad \frac{speed_{\sin\eta}}{speed_{\eta}} = \frac{\left(1 - e^{-q^2}\right)}{q^2}$$

BASICS OF STOCHASTIC EXTREMUM SEEKING

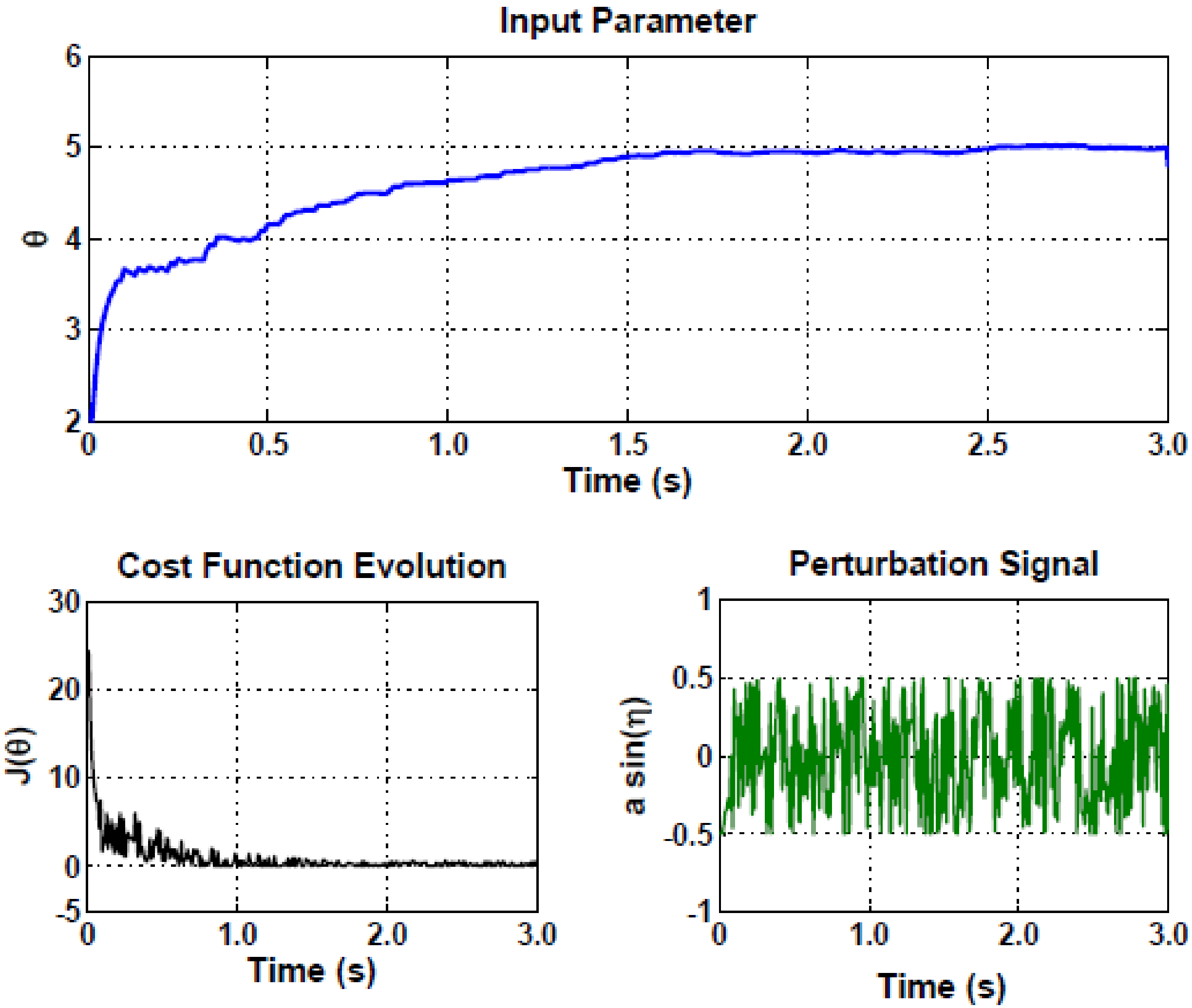
SIMULATION

$q = 1$

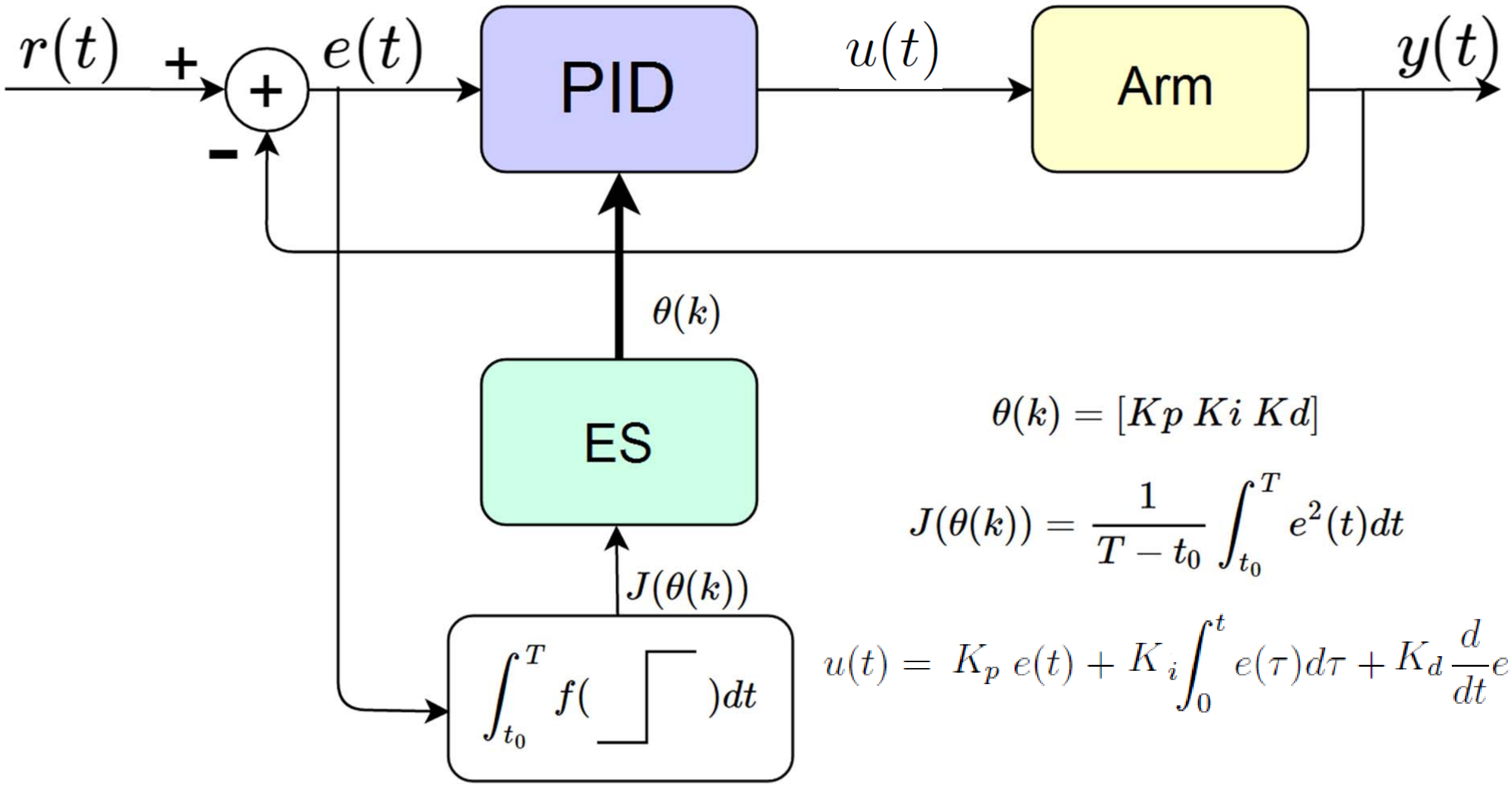
$\varepsilon = 0{,}25$

$a = 0{,}5$

$k = 10$



PROPOSED CONTROLLER (PID + ES)



$$\theta(k) = [Kp\; Ki\; Kd]$$

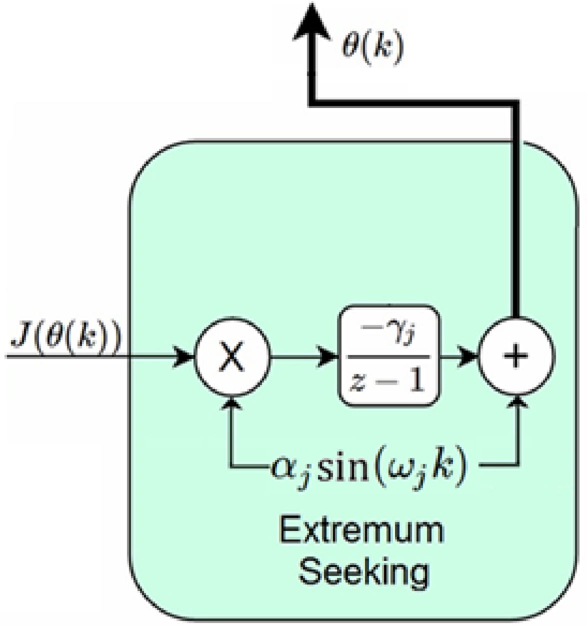
$$J(\theta(k)) = \frac{1}{T - t_0} \int_{t_0}^{T} e^2(t)dt$$

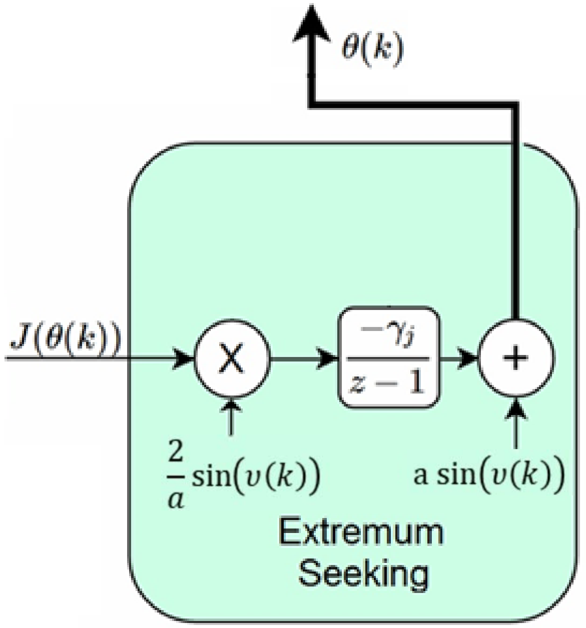
$$u(t) = K_p\, e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t)$$

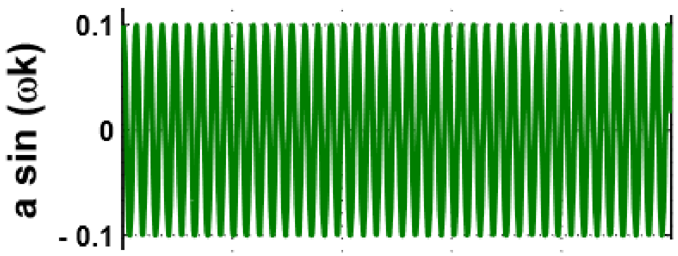
DETERMINISTIC versus STOCHASTIC EXTREMUM SEEKING

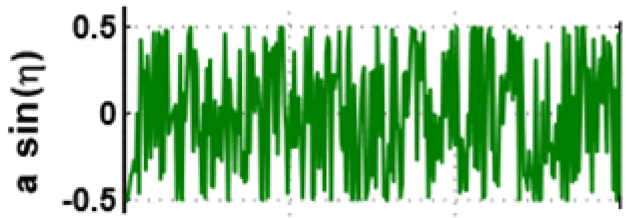
$$\hat{\theta}_i(k+1) = \hat{\theta}_i(k) - \gamma\alpha_i \sin(\omega_i k)\left[J(\theta(k))\right]$$

$$\hat{\theta}_i(k+1) = \hat{\theta}_i(k) - \beta\frac{2}{a}\sin(\nu_i(k))J(\hat{\theta}(k) + a\sin(\nu(k)))$$

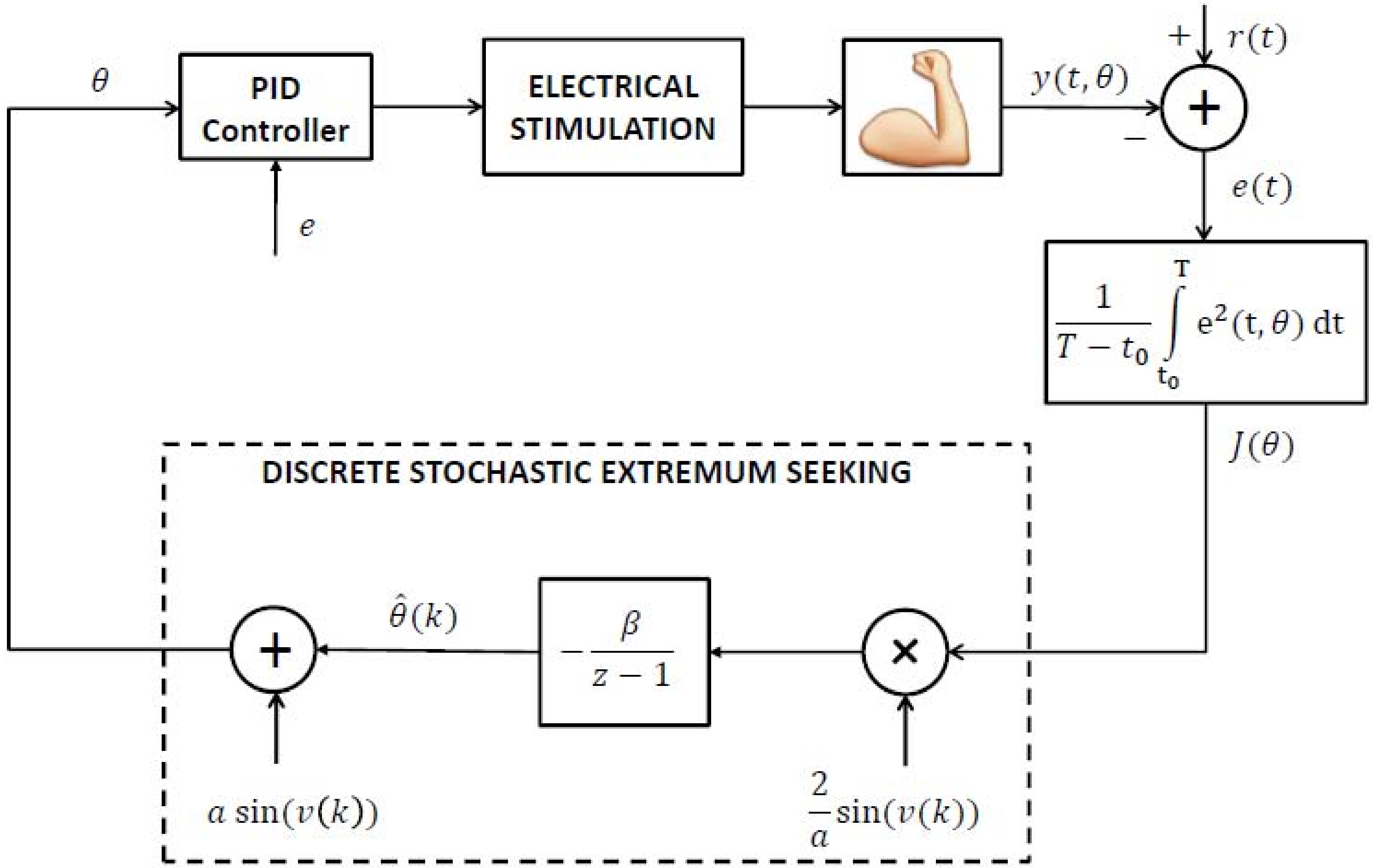






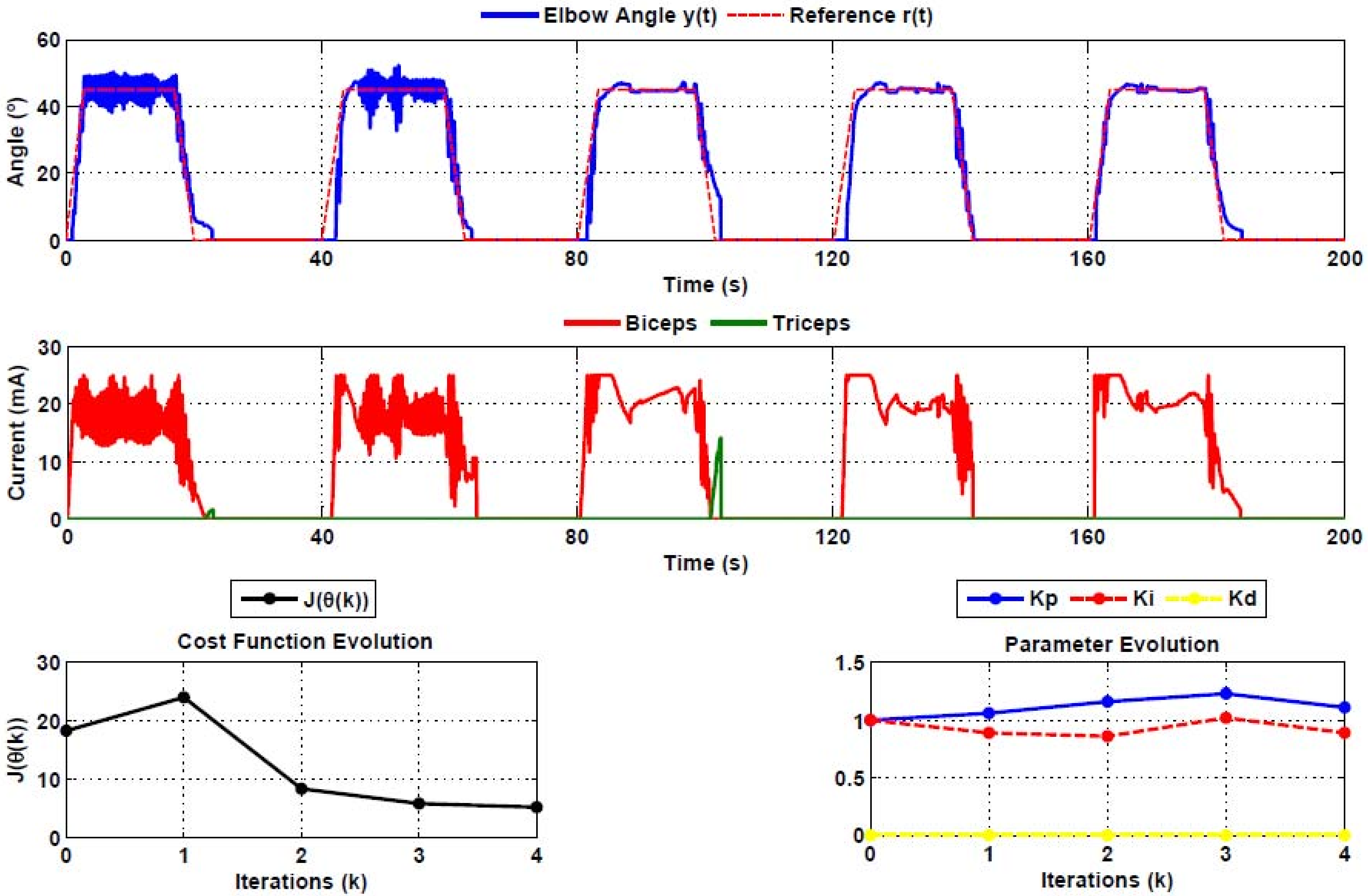


EXPERIMENTAL RESULTS



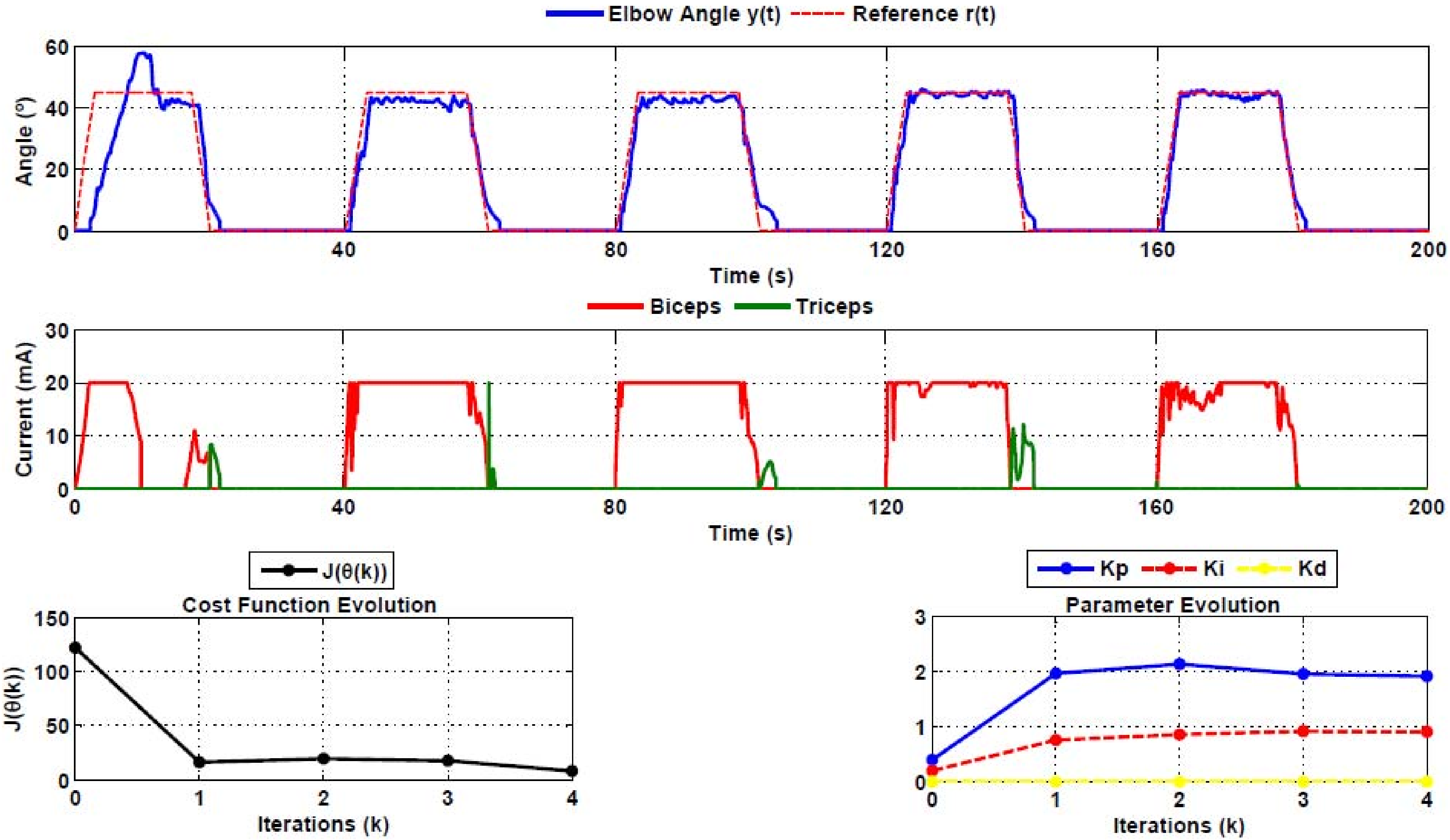
EXPERIMENTAL RESULTS

PATIENT 1



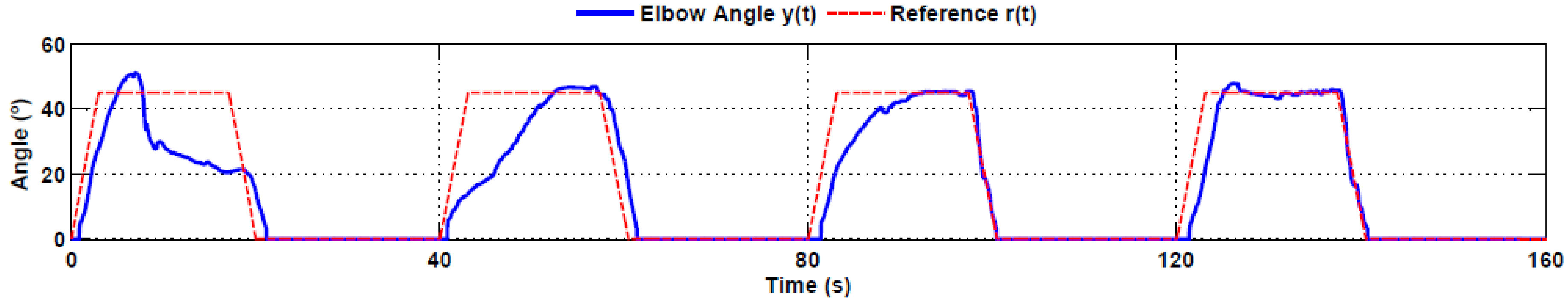
EXPERIMENTAL RESULTS

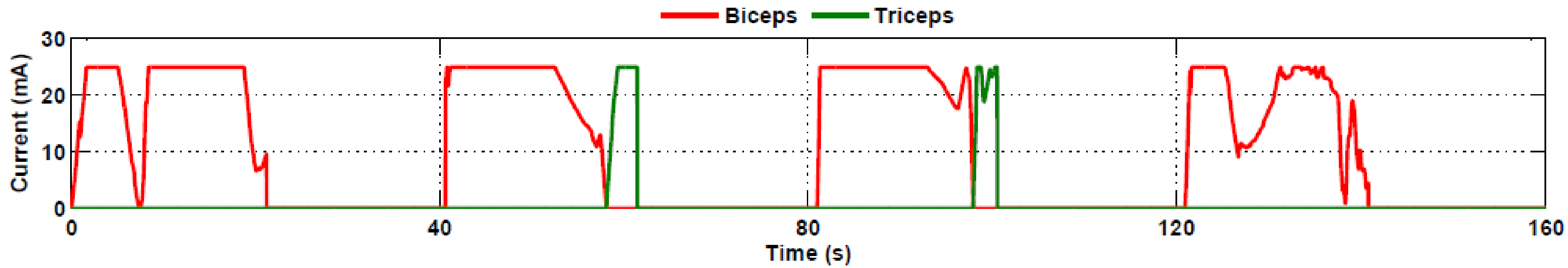
PATIENT 2

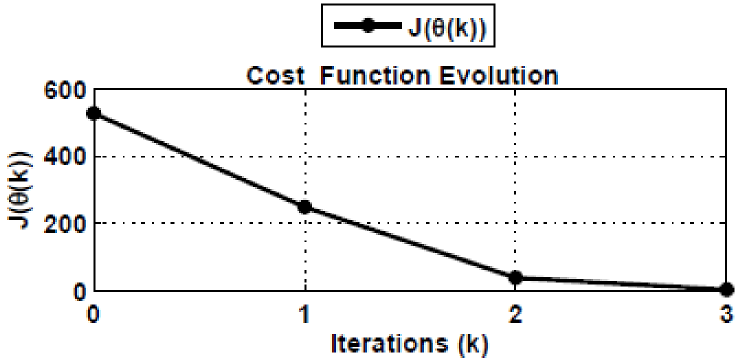


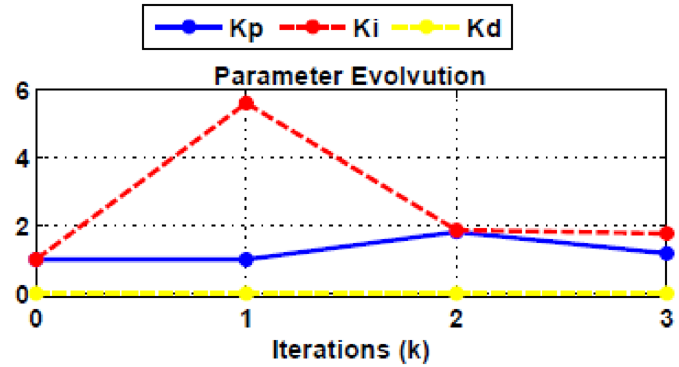
EXPERIMENTAL RESULTS

PATIENT 3



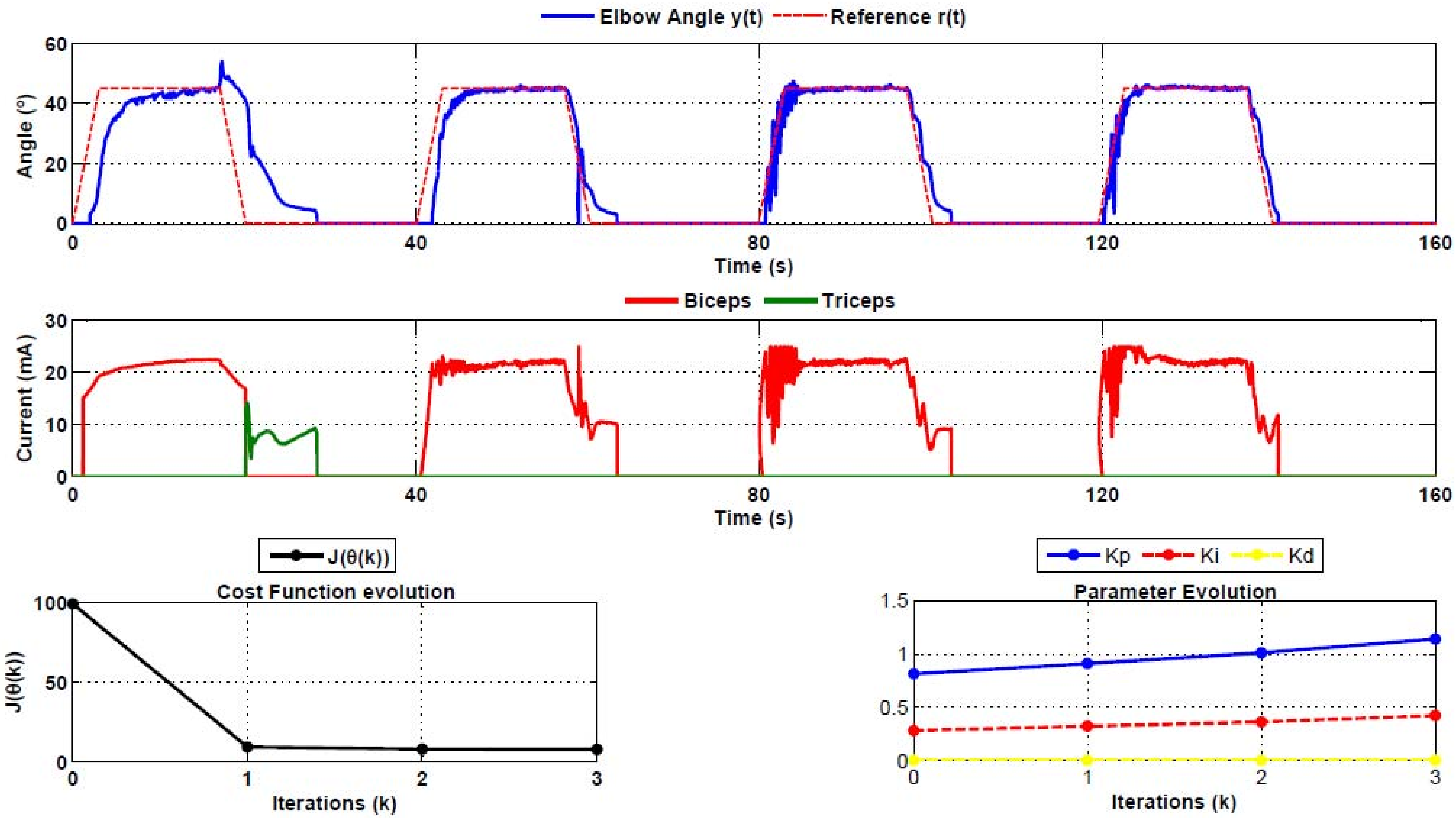






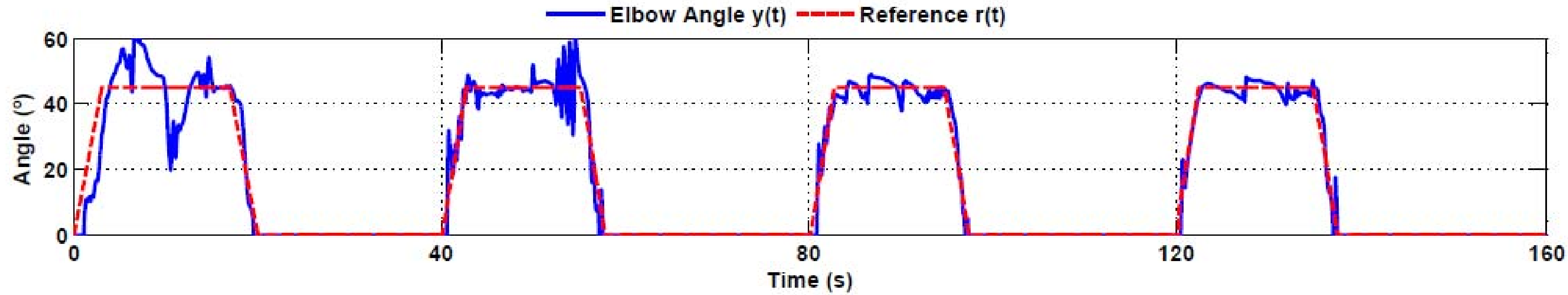
EXPERIMENTAL RESULTS

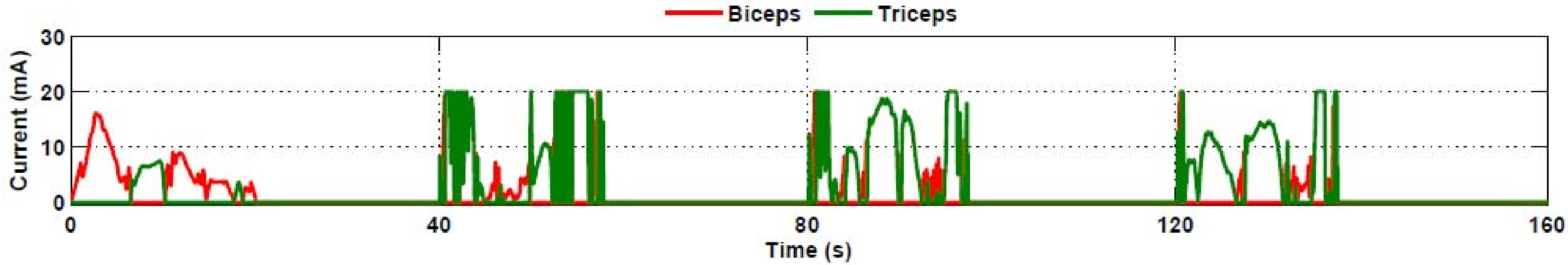
PATIENT 4

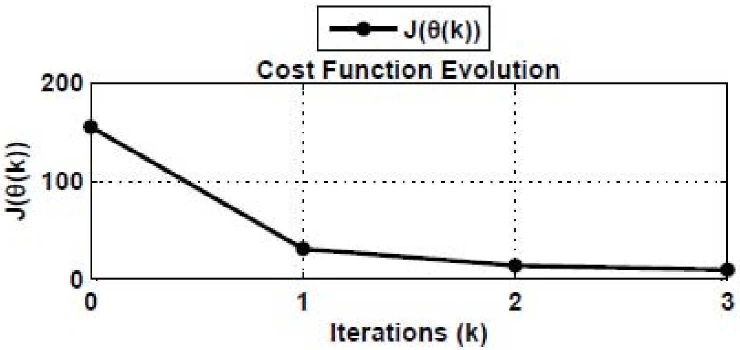


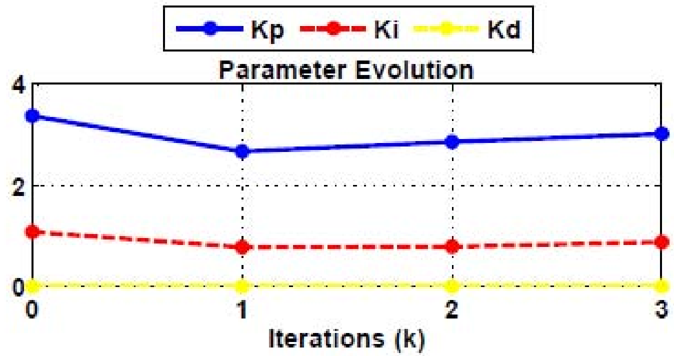
EXPERIMENTAL RESULTS

HEALTHY VOLUNTEER 1



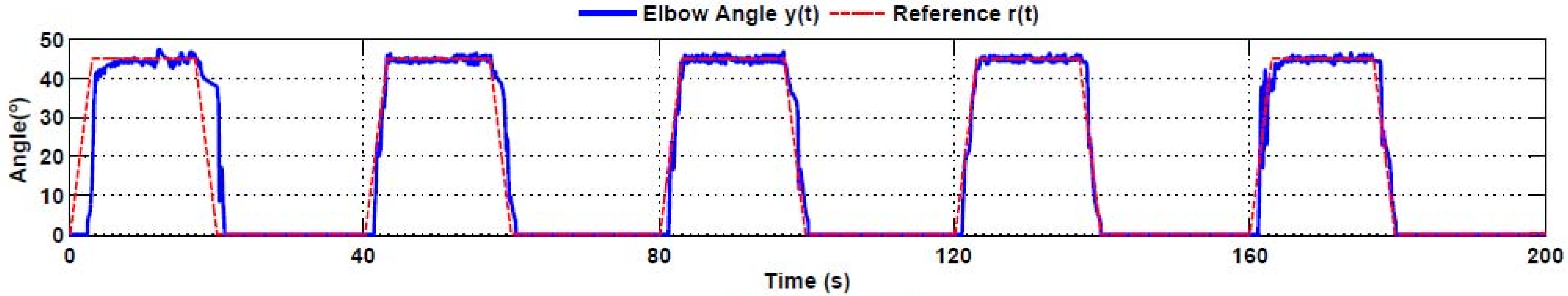


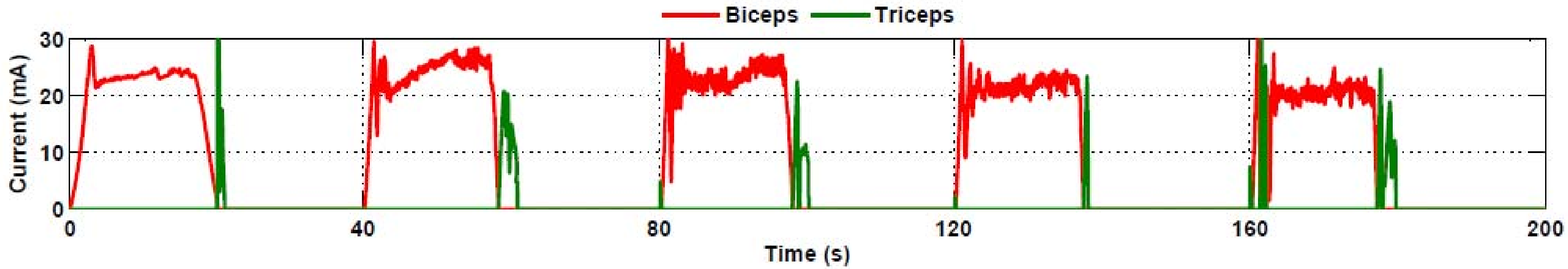


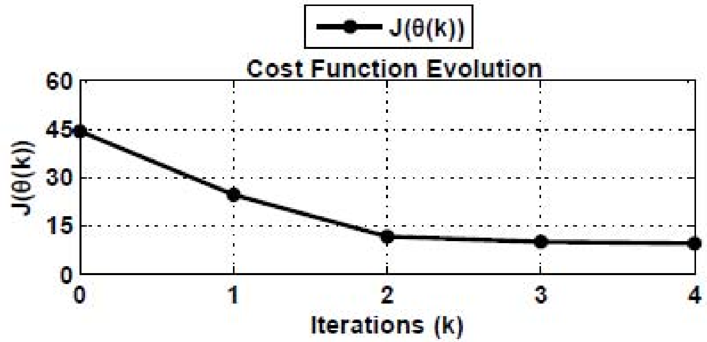


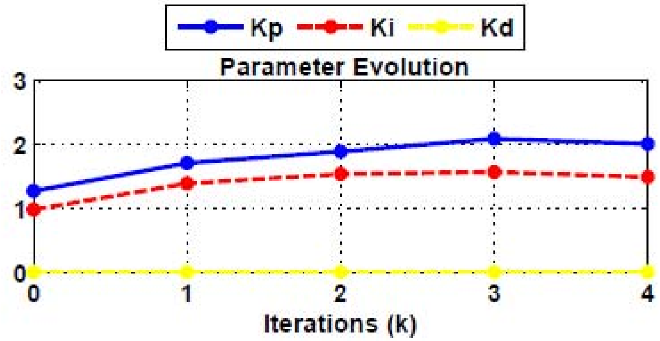
EXPERIMENTAL RESULTS

HEALTHY VOLUNTEER 2

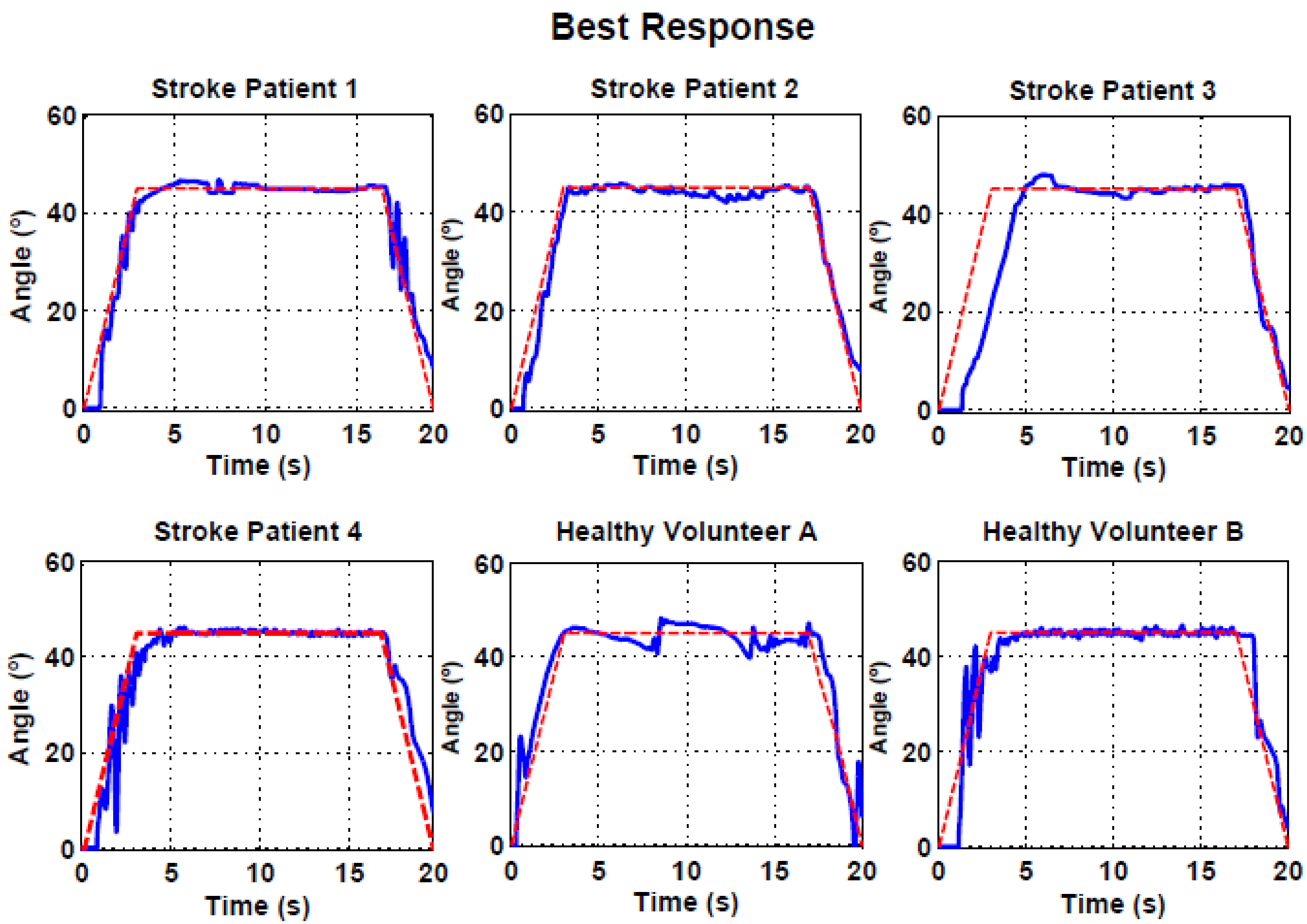






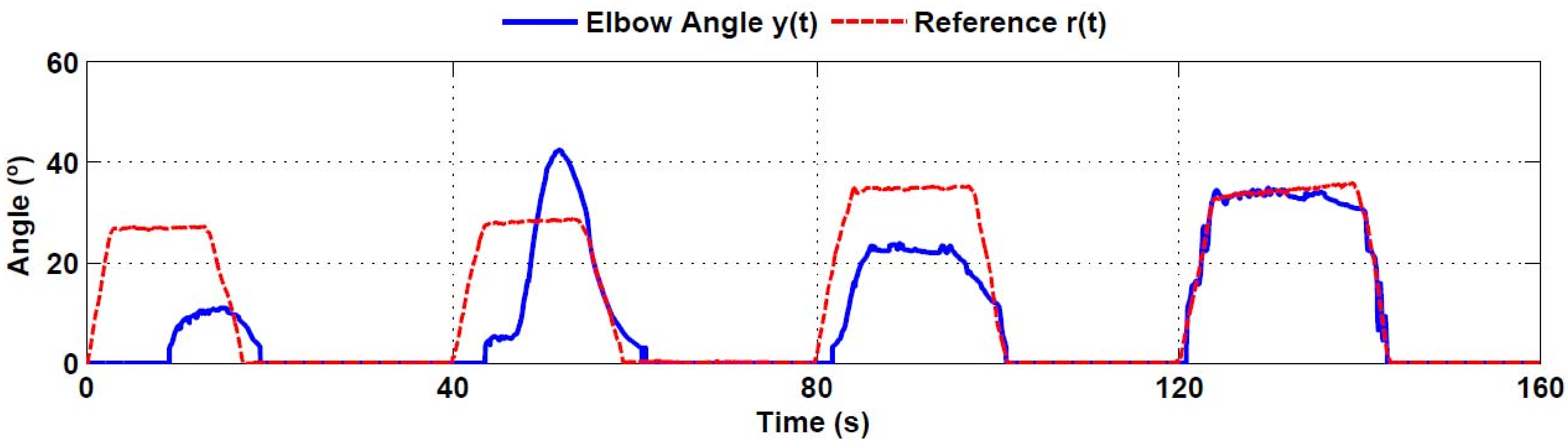


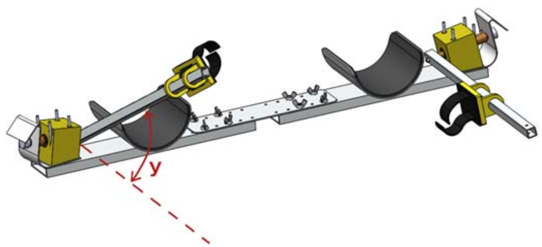
EXPERIMENTAL RESULTS

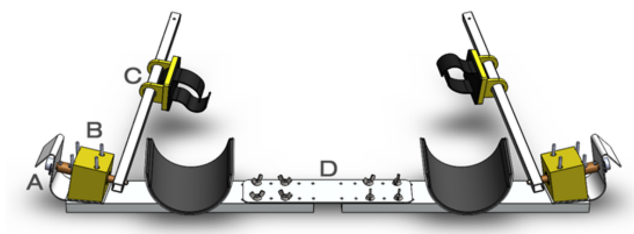


CONTRALATERAL MOVEMENT

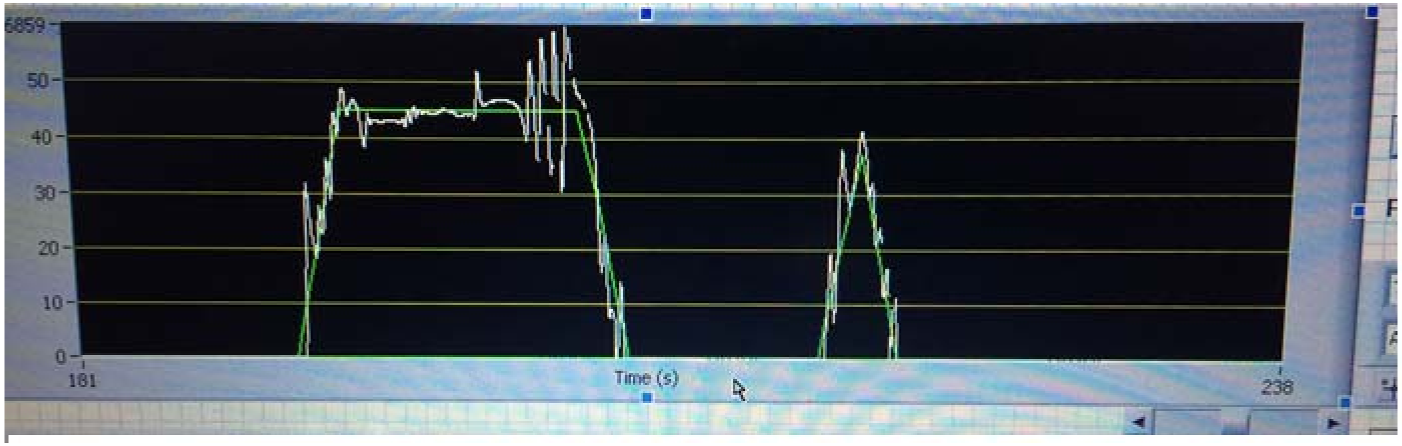
PATIENT 5

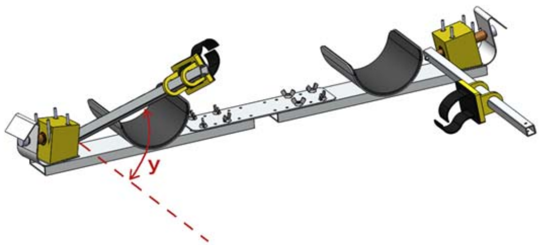


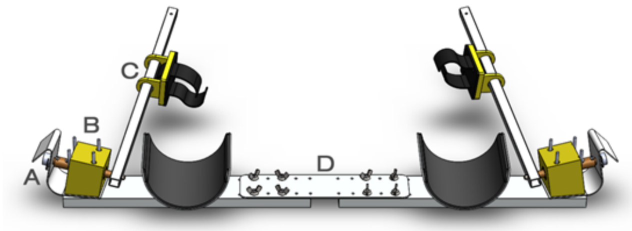




CONTRALATERAL MOVEMENT





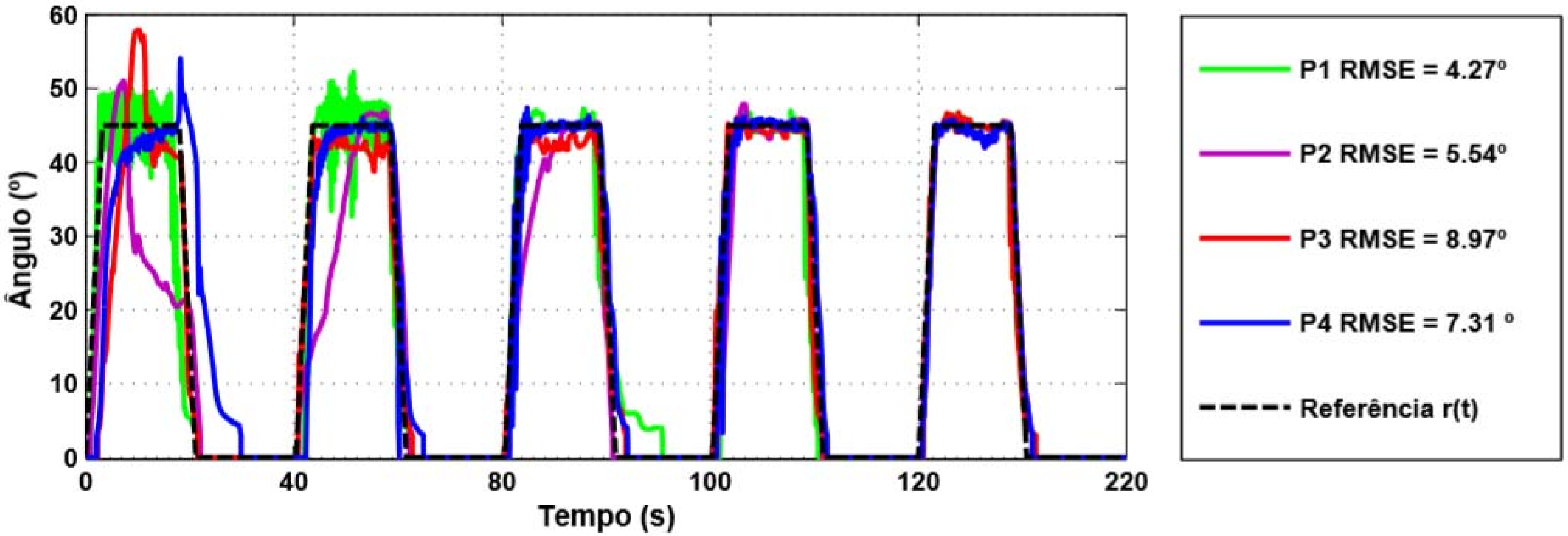


EXPERIMENTAL RESULTS OF 4 STROKE PATIENTS

CLINICAL DESCRIPTION OF THE STROKE PATIENTS AND BASIC INFORMATION OF THE HEALTHY VOLUNTEERS

Subject	Age	Gender	Lesion Time (months)	Lesion Side	Stroke Type	MAS Scale[1]	Rankin Scale[2]	FMA-MS[3]
P1	40	M	121	L	H	3	III	14/66
P2	53	M	134	R	I	1+	I	26/66
P3	28	F	69	R	I	2	I	36/66
P4	59	F	162	L	H	2	III	9/66
P5	35	M	18	R	I	1+	I	18/66
VA	33	F	-	-	-	-	-	-
VB	31	M	-	-	-	-	-	-

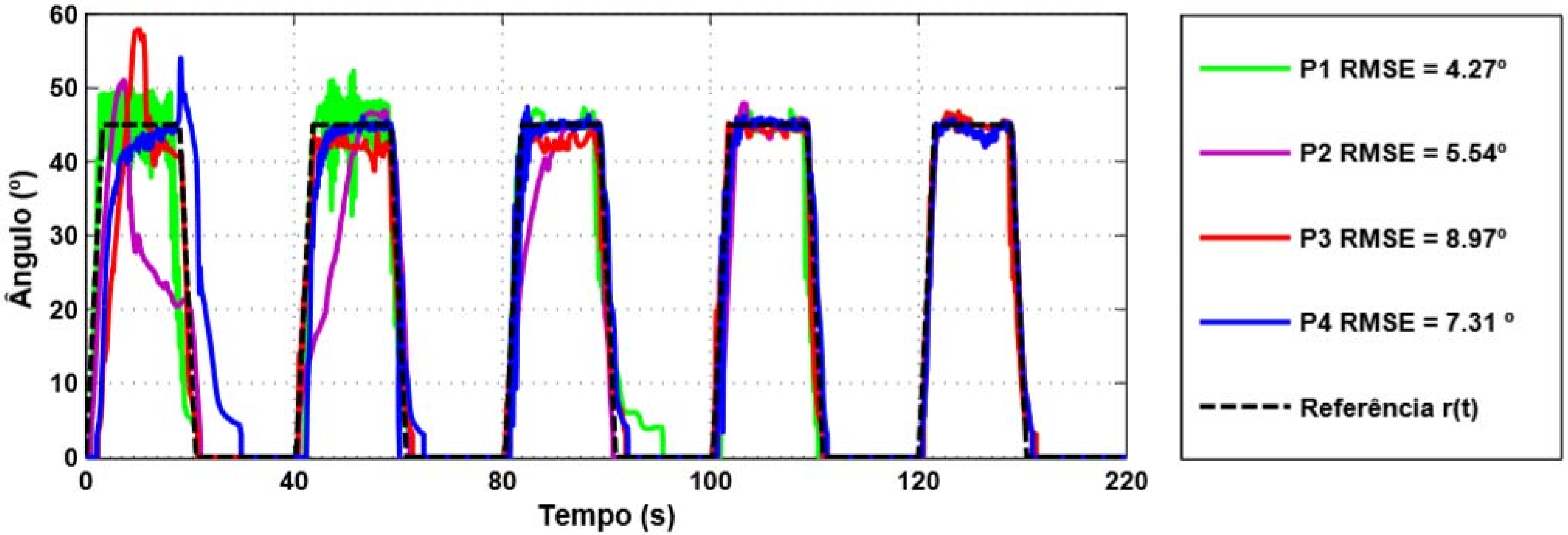
M - Male, F- Female, R - Right, L - Left, I - Ischemic Stroke, H - Hemorrhagic Stroke
1 - Modified Ashworth Scale
2 - Stroke Severity Scale
3 - Upper Limb Fugl-Meyer Assessment Scale



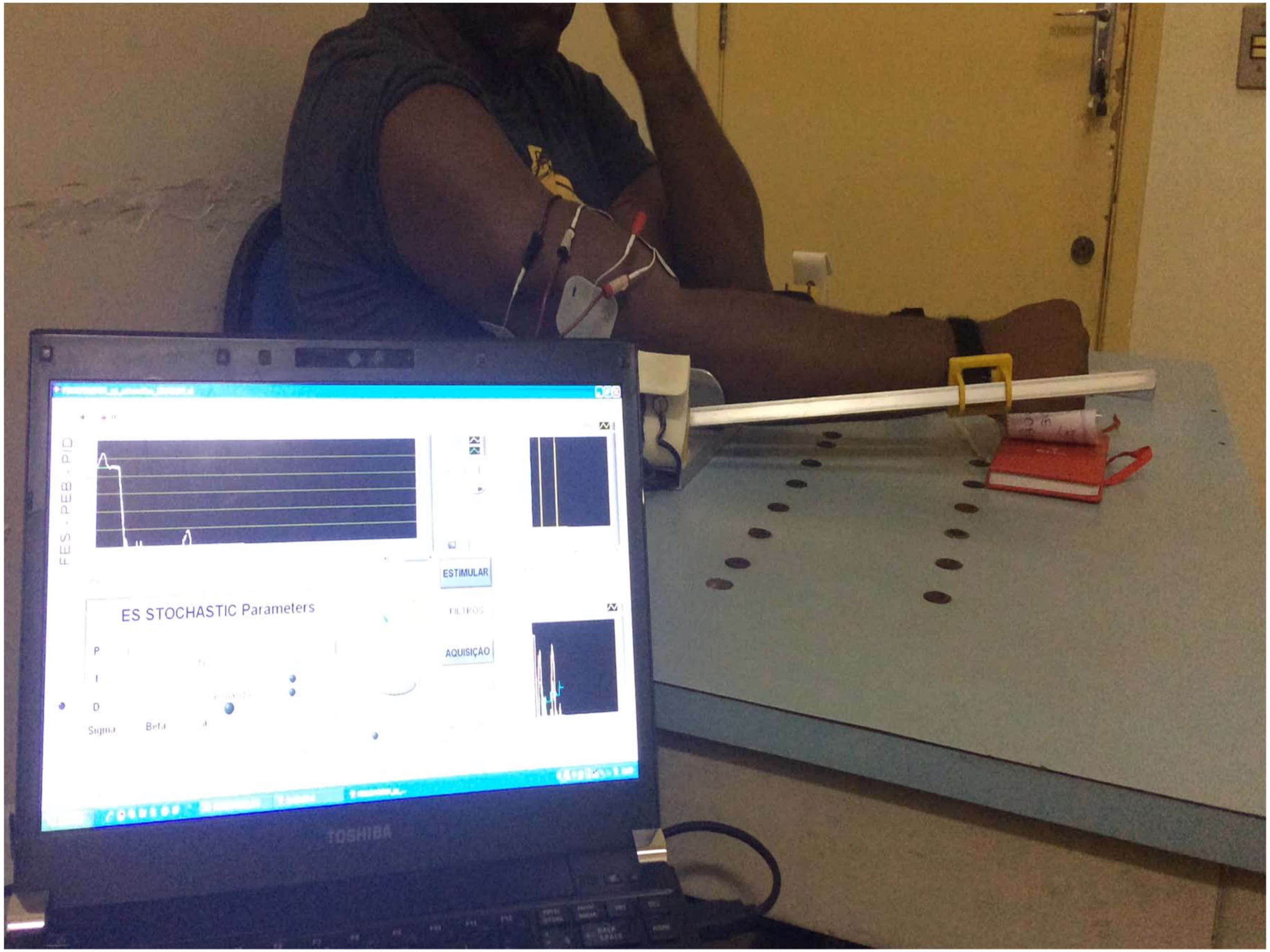
EXPERIMENTAL RESULTS OF 4 STROKE PATIENTS

Root-Mean-Square Error (RMSE) obtained for stroke patients and healthy volunteers

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Volunteer A	Volunteer B	Mean
Total RMSE	4.27°	5.54°	8.97°	7.31°	4.91°	4.02°	5.13°	5.73°
RMSE of First Cycle	3.62°	10.88°	10.98°	12.61°	8.94°	6.68°	9.49°	9.02°
RMSE of Last Cycle	2.51°	2.26°	5.72°	3.17°	5.22°	2.04°	2.94°	3.40°



REAL EXPERIMENT WITH STROKE PATIENT



CONCLUSION

✓ Stochastic Extremum Seeking-based PID is a self-tuning, fatigue resistant control method for NMES-based therapies.

✓ In spite of the nonlinearities and time-varying properties of the NMES process, it was satisfactorily approached by the proposed adaptive PID controller via stochastic ES.

✓ Good tracking performance can be achieved after reduced number of the algorithm iteractions.

✓ According to our experiments, the proposed adaptive control approach had presented good performance results to reach the target angle.

TALKS AND PUBLICATIONS




TALKS AND PUBLICATIONS

Congresso Brasileiro de Automática

CBA2018

XXII Congresso Brasileiro de Automática

João Pessoa - PB, Brasil: 9/9/2018 to 12/9/2018

Conference Proceedings ISSN: 2525-8311

BUSCA EXTREMAL ESTOCÁSTICA APLICADA À ESTIMULAÇÃO ELÉTRICA NEUROMUSCULAR EM PACIENTES COM AVC

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[1]Universidade do Estado do Rio de Janeiro (UERJ)

doi:10.20906/CPS/CBA2018-0726

Abstract

A técnica de Busca Extremal Estocástica (Stochastic Extremum Seeking - ES) é aplicada para adaptar os ganhos de um controlador Proporcional-Integral-Derivativo (PID) na estimulação elétrica neuromuscular. O esquema proposto é aplicado no controle da posição do braço depacientes com sequelas de Acidente Vascular Cerebral (AVC) para coordenar os movimentos de

TALKS AND PUBLICATIONS

Busca Extremal Estocástica Aplicada à Estimulação Elétrica Neuromuscular

UFRJ

UERJ — UNIVERSIDADE DO ESTADO DO RIO DE JANEIRO

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INTRODUÇÃO

A técnica de Busca Extremal Estocástica (*Stochastic Extremum Seeking* - ES) é aplicada para adaptar os ganhos de um controlador Proporcional - Integral-Derivativo (PID) na estimulação elétrica neuromuscular (NMES). O esquema proposto é aplicado no controle da posição do braço de pacientes com seqüelas de Acidente Vascular Cerebral (AVC) para coordenar os movimentos de flexão e extensão dos braços. Esta abordagem elimina os testes iniciais de sintonia e os parâmetros do controlador são automaticamente computados em tempo real. Os parâmetros PID são ajustados através de uma versão discreta multivariável do ES estocástico para minimizar uma função de custo que representa o desempenho dos requisitos desejados.

Figura 1 - Aparato mecânico para testes experimentais NMES.

Busca Extremal Estocástica

TALKS AND PUBLICATIONS

2018 IEEE Conference on Decision and Control (CDC)
Miami Beach, FL, USA, Dec. 17-19, 2018

Neuromuscular Electrical Stimulation for Stroke Patients by Deterministic Extremum Seeking

Paulo Paz[1] and Tiago Roux Oliveira[1]

***Abstract*— A multiparameter and deterministic extremum seeking (ES) algorithm is applied to tune Proportional-Integral-Derivative (PID) controllers for functional neuromuscular electrical stimulation (NMES). The proposed scheme controls the patient's arm such that the desired movements of flexion/extension for its elbow can be generated. The PID tuning using ES eliminates initial off-line tests with patients since the control gains are automatically computed in order to minimize a cost function according to the tracking error between the elbow's angle and the reference trajectory. Experiments with eight stroke patients show advances in terms of reduced root-mean-square error (RMSE) and improved ultimate responses when compared to the initial evaluation cycle.**

I. INTRODUCTION

Functional Electrical Stimulation (FES) or Neuromuscular may be totally unproductive. The adverse environment of modeling inspires the application of adaptive-robust control methodologies and automatic tuning techniques [6].

The purpose of this paper is to develop an adaptive PID control scheme for NMES, aimed to upper limb unilateral exercises, by evaluating its operation with *stroke patients*. The proposed method for online tuning PID parameters using multivariable and deterministic Extremum Seeking (ES) [7] within a closed-loop setting is shown to be importantly fruitful. As discussed in our previous publication [9] with healthy volunteers, there are clear advantages in applying deterministic (periodic) excitation rather than more classical methods for PID tuning when dealing with nonlinear systems [8]. The proposed adaptive algorithm based on periodic

TALKS AND PUBLICATIONS

This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

Model-Free Neuromuscular Electrical Stimulation by Stochastic Extremum Seeking

Paulo Paz, Tiago Roux Oliveira, Alexandre Visintainer Pino, and Ana Paula Fontana

***Abstract*—Stochastic extremum seeking (ES) approach is employed to adapt the gains of a proportional—integral—derivative (PID) control law for functional neuromuscular electrical stimulation. The proposed scheme is applied to control the position of the arm of healthy volunteers and stroke patients so that coordinated movements of flexion/extension for their elbow can be performed. This approach eliminates the initial tuning tests with patients since the controller parameters are automatically computed in real time. The PID parameters are updated by means of a discrete version of multivariable stochastic ES in order to minimize a cost function which brings the desired performance**

as stroke patients) to perform movements that would not be able to be executed.

NMES can be separated into two segments: functional substitution and therapeutic intervention. For instance, stroke patients with drop foot [2] use NMES to activate the tibialis anterior muscle during swing phase. In this situation, NMES is used as a functional substitute of a damaged central nervous system which is not able to recruit the necessary muscles during the gait. Differently, patients making repetitive and

IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY

TALKS AND PUBLICATIONS

Anais da Academia Brasileira de Ciências (2019) 91(Suppl. 1) e20180544
(Annals of the Brazilian Academy of Sciences)
Printed version ISSN 0001-3765 / Online version ISSN 1678-2690
http://dx.doi.org/10.1590/0001-3765201820180544
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ACADEMIA BRASILEIRA DE CIÊNCIAS

Extremum Seeking-based Adaptive PID Control applied to Neuromuscular Electrical Stimulation

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Manuscript received on May 30, 2018; accepted for publication on August 13, 2018

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Questions & Comments

Contact: tiagoroux@uerj.br

Supported by:

CNPq
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Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro