Design of an emotion-based controller for dynamical systems

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Dissertation Defense

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UNIVERSIDAD NACIONAL DE COLOMBIA

LISI Laboratorio de investigación en sistemas inteligentes

UNIVERSIDAD DISTRITAL FRANCISCO JOSÉ DE CALDAS

Outline

Research problem

Problem statement
Significance of the research
Research questions

Solution

State of the art
Proposed controller
Results

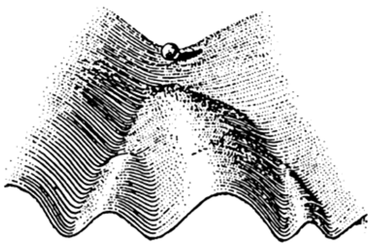
Conclusions and future work

Constraints
Conclusions
Future work

Problem statement (1/2)

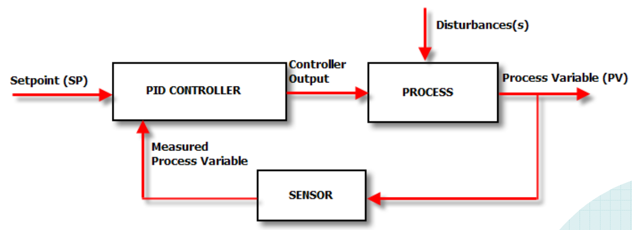
- Traditional controllers are based on **mathematical approaches** → simple systems

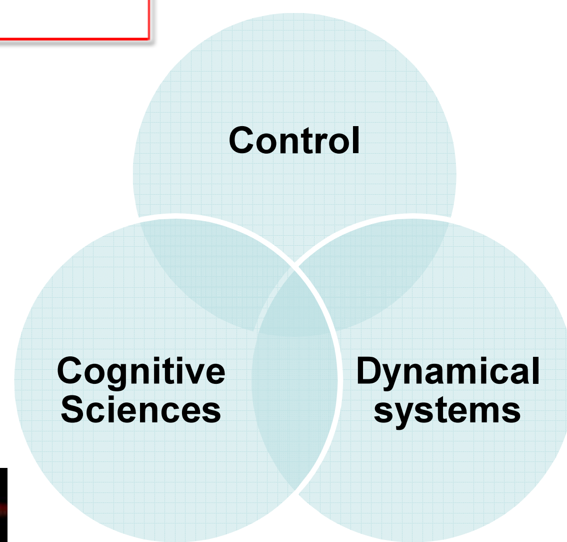
- Systems are **nonlinear** and **variant**

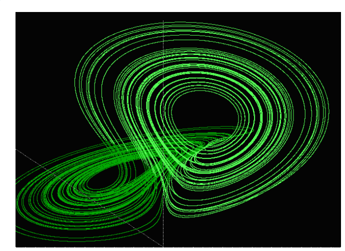


- Traditional control techniques depend on an **identification** process, but systems are only partially known
- Any change may cause poor performance or even **instability**

Problem statement (2/2)





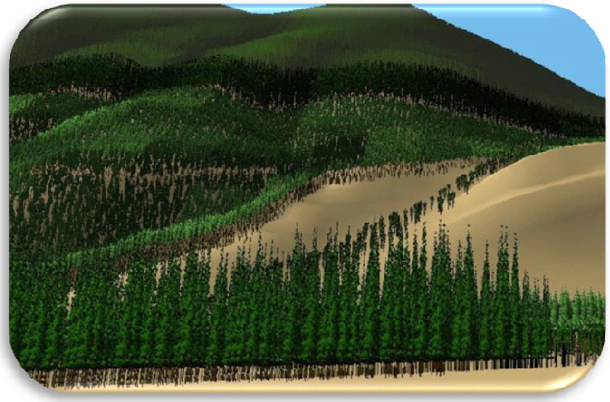


Significance of this research

Motion planning

Fault tolerance

Complex systems



High order systems

Research questions

- Being human emotions essential in **decision making**, could they be introduced in a controller?
- How to **emulate** human emotions given a dynamical system?
- Can emulated emotions improve the **performance** of a controller for dynamical systems **in contrast** to traditional controllers?
- Would every human emotion be useful to control dynamical systems, or just a **set of them**?
- What other **brain capabilities** may be important to introduce in a control algorithm?

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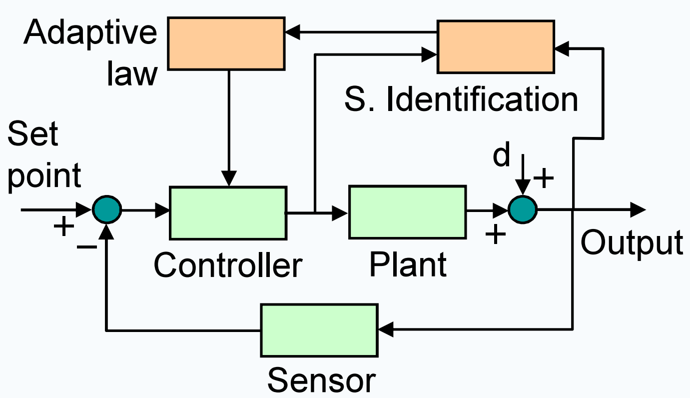
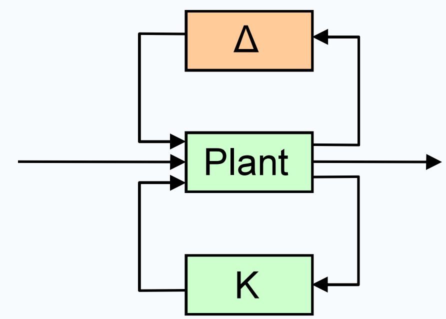
State of the art (1/5)

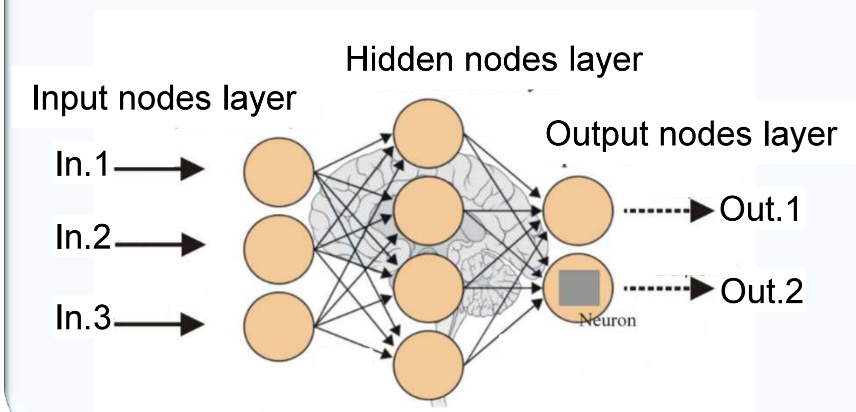
Adaptive control systems



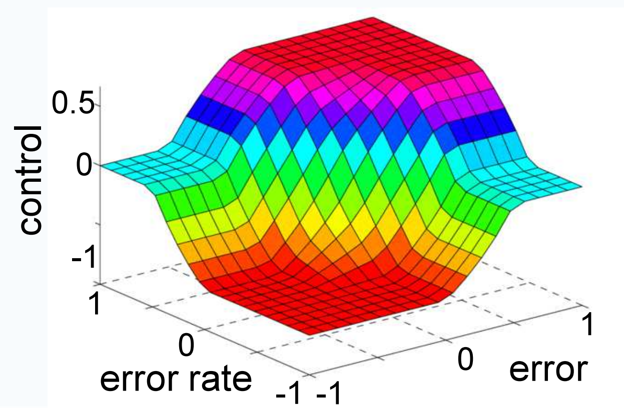
Robust control systems



Neural network control



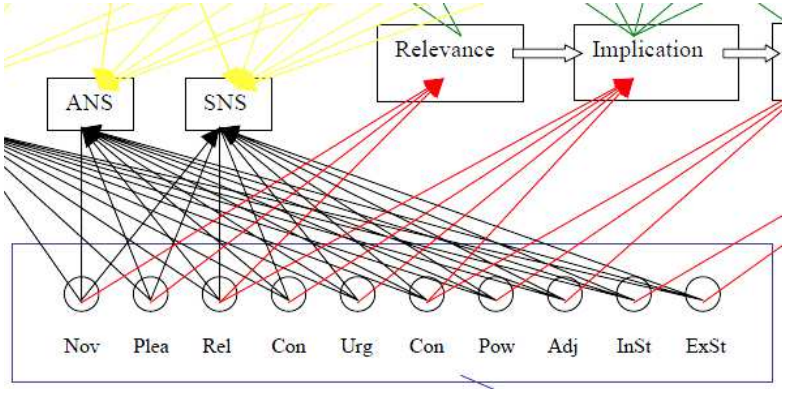
Fuzzy logic control



State of the art (2/5)

- Discrete theory of emotions
  Robert Plutchik, Paul Ekman, and Nico Frijda.

- Appraisal theory of emotions
  Richard Lazarus and Craig Smith.
  Suddenness, importance of the goal, control, available energy, among other aspects



State of the art (3/5)

Neuroscience models

EEG, PET, MEG, MRI, fMRI

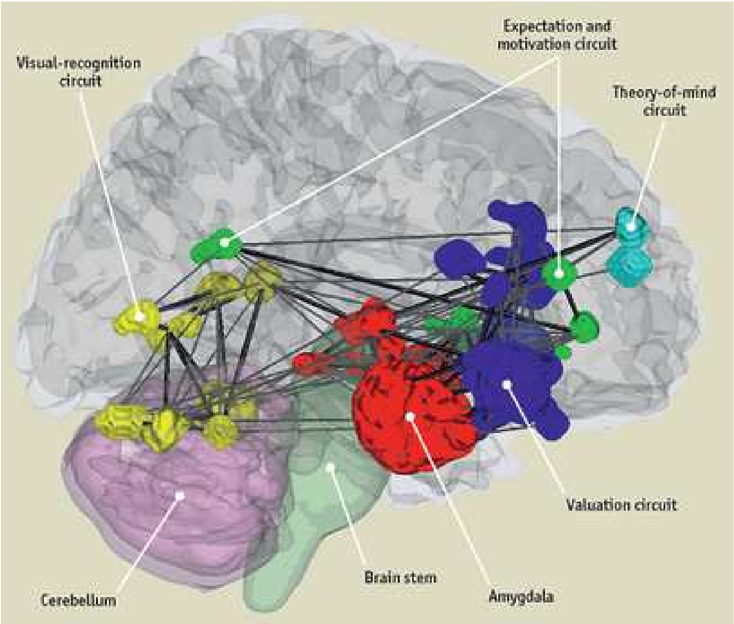
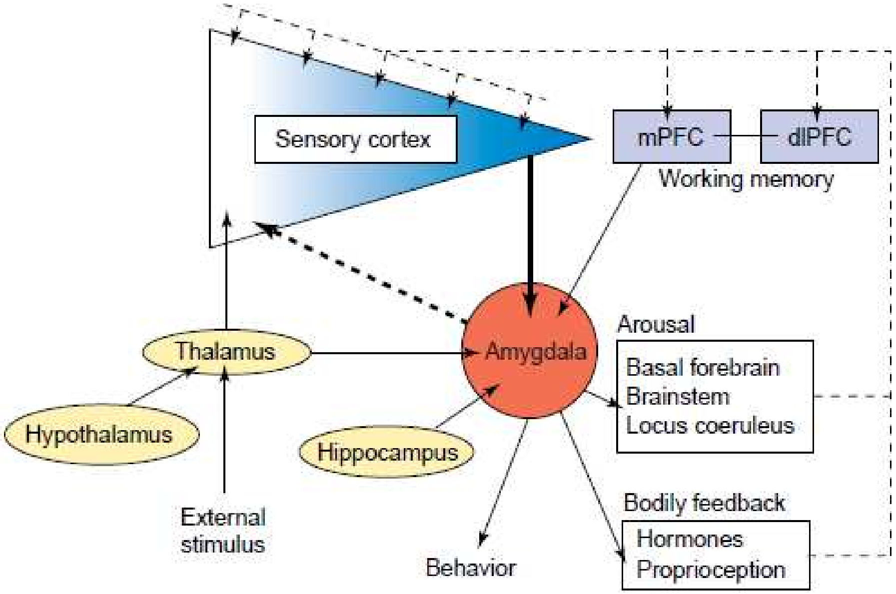


Figure taken from “The Economist”,
Special report, the brain, 2006

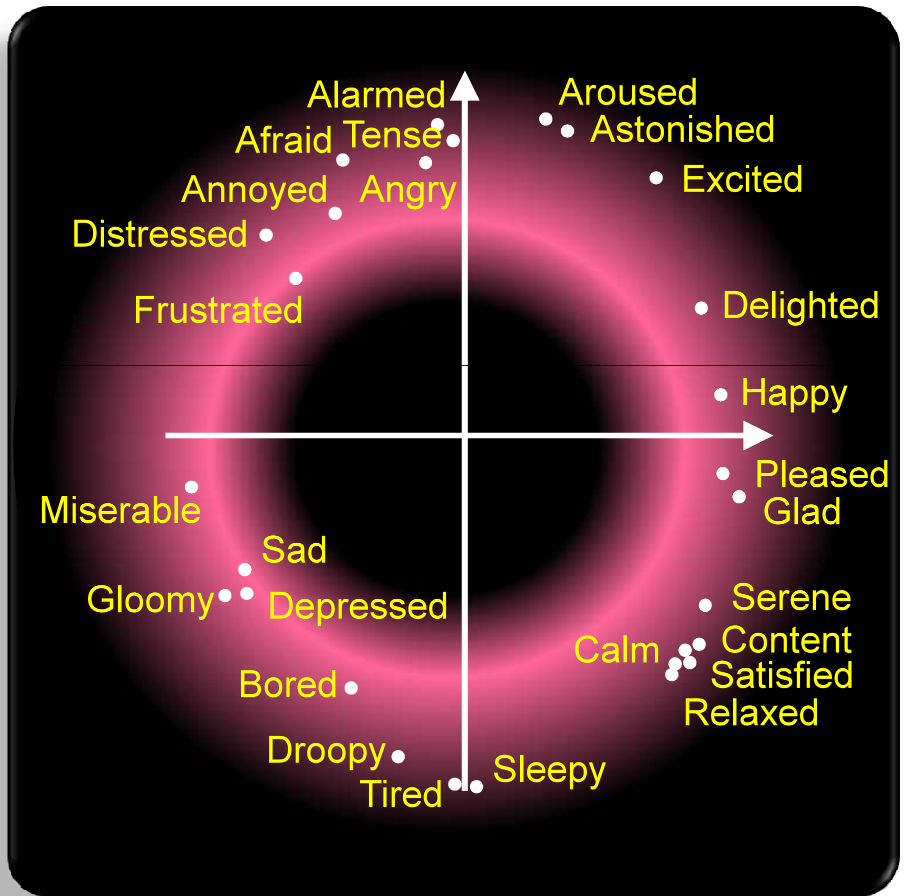
Fear circuit of Joseph Ledoux



Emotions, from brain to robot, 2004
Trends in Cognitive Sciences

State of the art (4/5)

Circumplex model of affect (CMA), Rusell, 1980



X → Valence (-,+)
Y → Arousal (H,L)

Applications of the CMA:
Music, Psychology, Affective computing, Human Computer Interaction, Linguistics, Medicine, Robotics

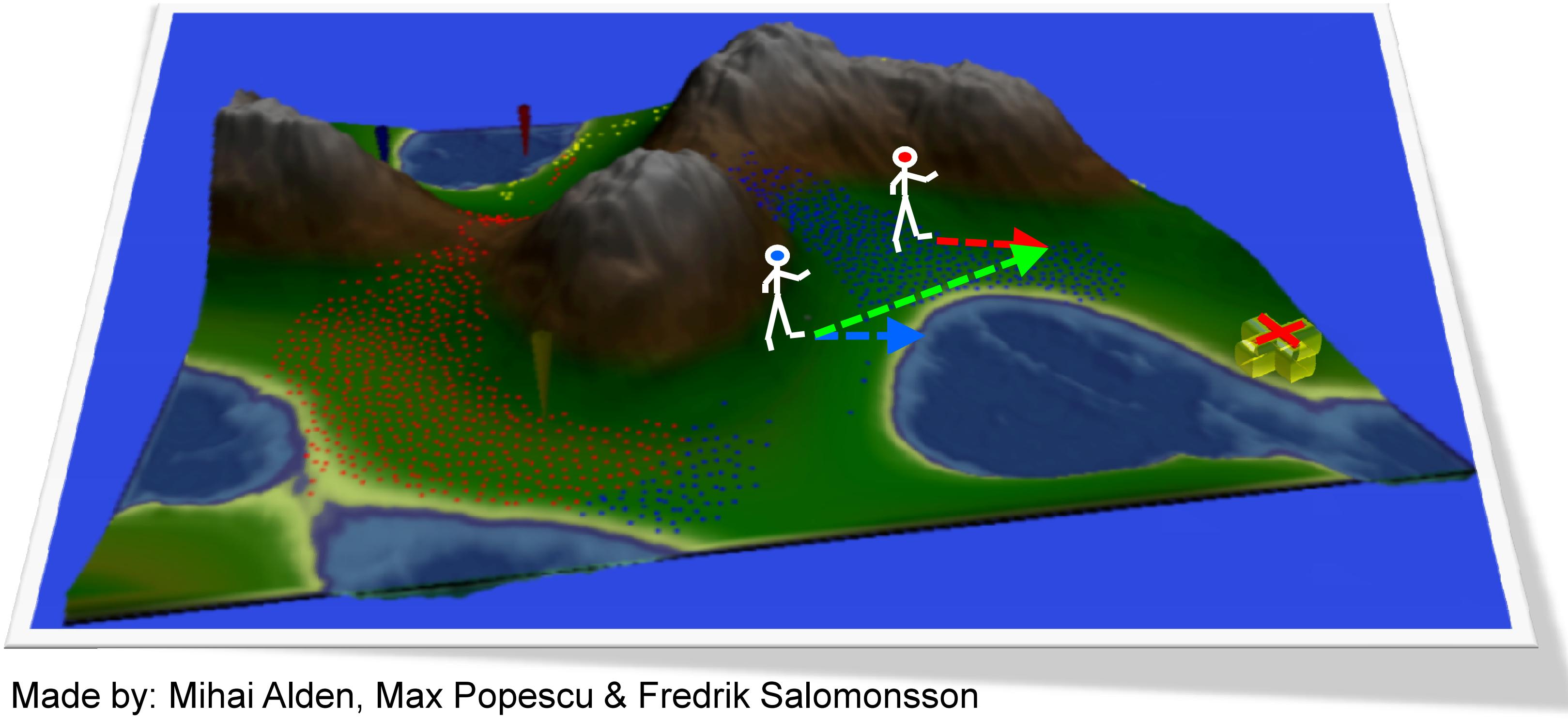
State of the art (5/5)

- Emotions result from **the comparisons between an alternative situation and a reference**.
  Aaron Ben-Zeev, “The Subtlety of Emotions” MIT, 2000

- Emotions are **caused by the discrepancy between perceived reality and one’s desires**.
  Franklin E. Payne, “A Definition of Emotions” JBEM, 2003

Proposed approach

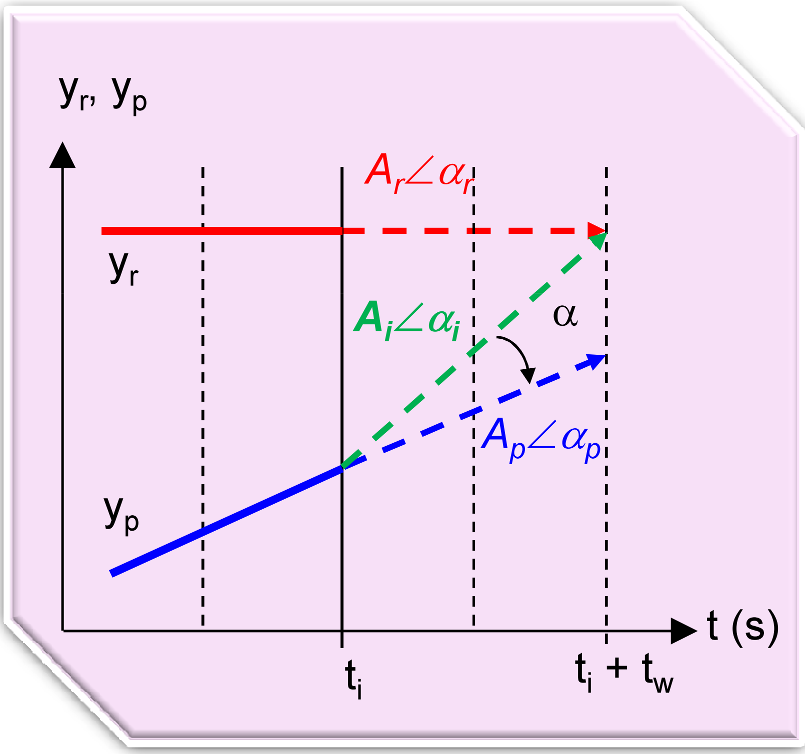
Intuition



Made by: Mihai Alden, Max Popescu & Fredrik Salomonsson
Computer Models of Cognitive Processes, MT, LiU, 2010

Proposed controller (1/4)

Emotional state /
Emotional intensity

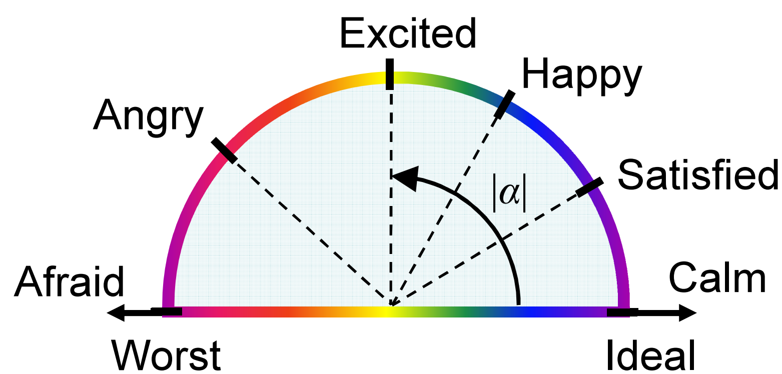


α: emotional state

$$\alpha = a\tan\left(\frac{y_r(t_i + t_w) - y_p(t_i)}{t_w}\right) - a\tan\left(\frac{y_p(t_i + t_w) - y_p(t_i)}{t_w}\right)$$

A_i: emotion intensity

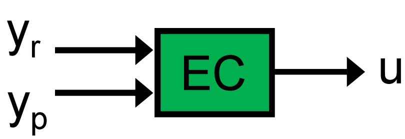
$$A_i = \sqrt{\left(y_r(t_i + t_w) - y_p(t_i)\right) + t_w^2}$$



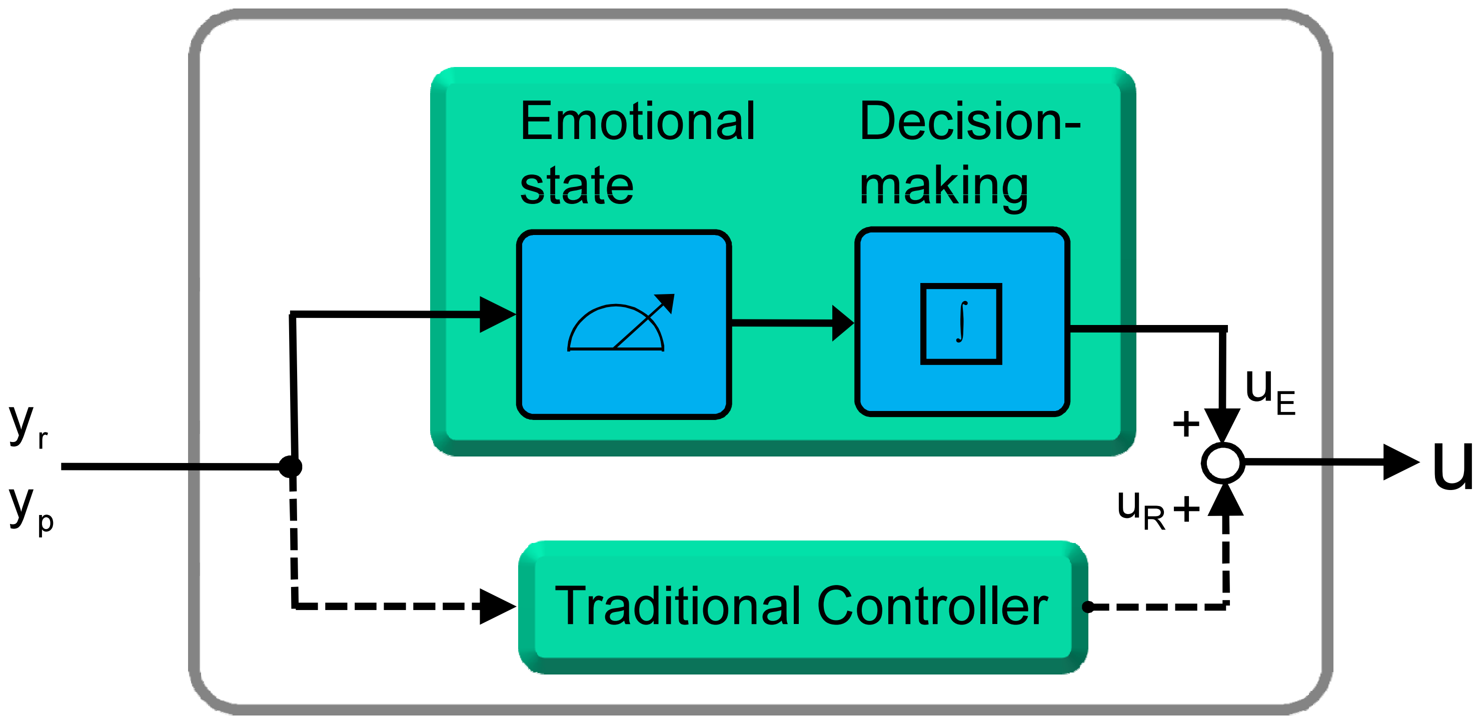
Emotional state

Proposed controller (2/4)

Control architecture

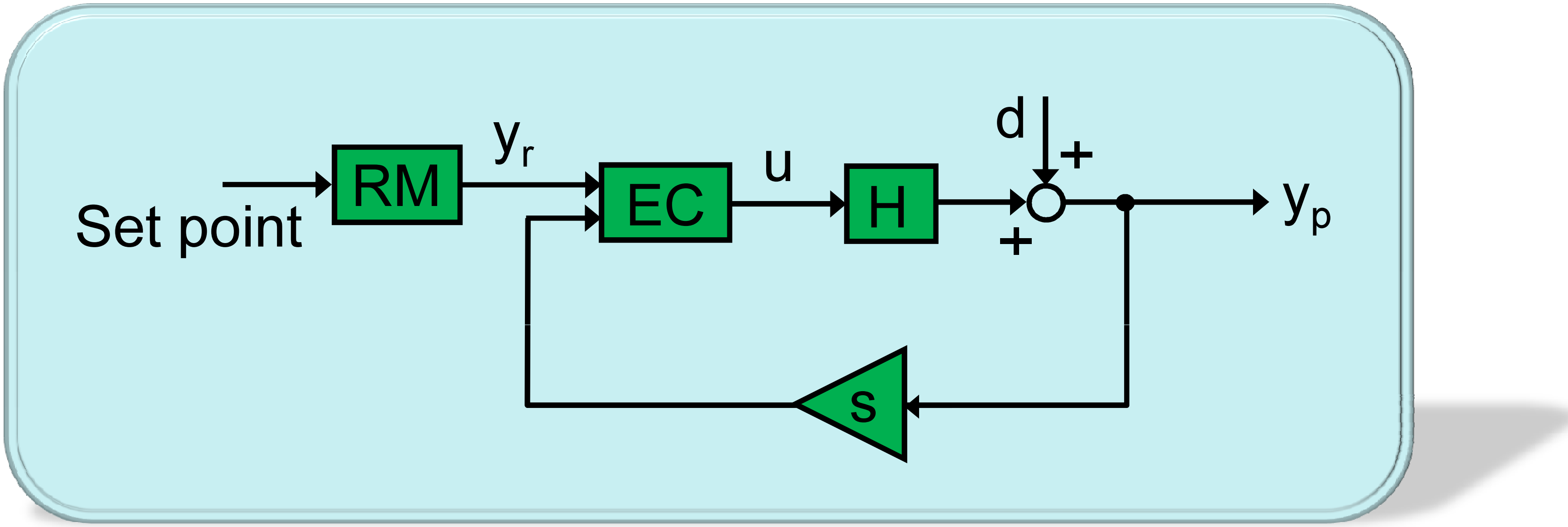


Emotional-based controller



Proposed controller (3/4)

Emotion-based control systems



The emotion-based controller **EC** looks to match the plant's dynamic to the reference dynamic **RM**, regardless of changes in **d** or in the system **H**.

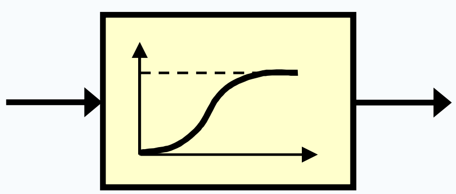
Proposed controller (4/4)

Reference Model (RM)

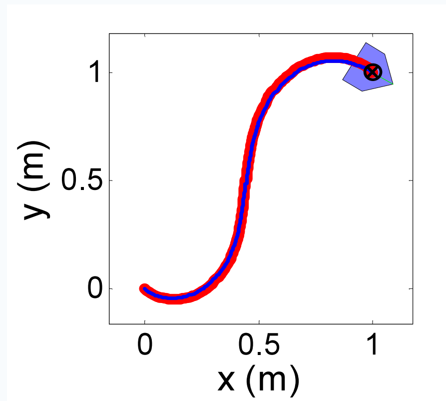
Current control techniques using RM:

Model Reference Control: NN
Model Reference Robust Control
Model Reference adaptive control
Model Predictive Control

Two examples:



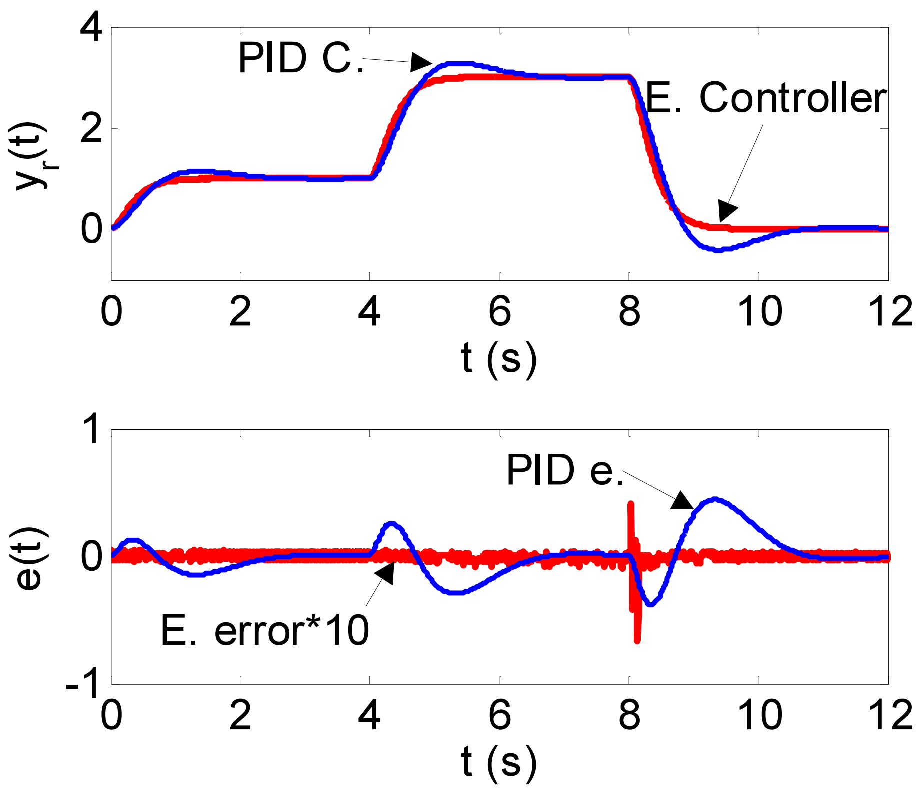
ITAE, Bessel
Buttherworth, Chebyshev



A reference model might result from an identification process

Results (1/9)

Controlling an unstable plant



- **Plant**:

$$H = \frac{1}{S-1}$$

- **Reference model**:

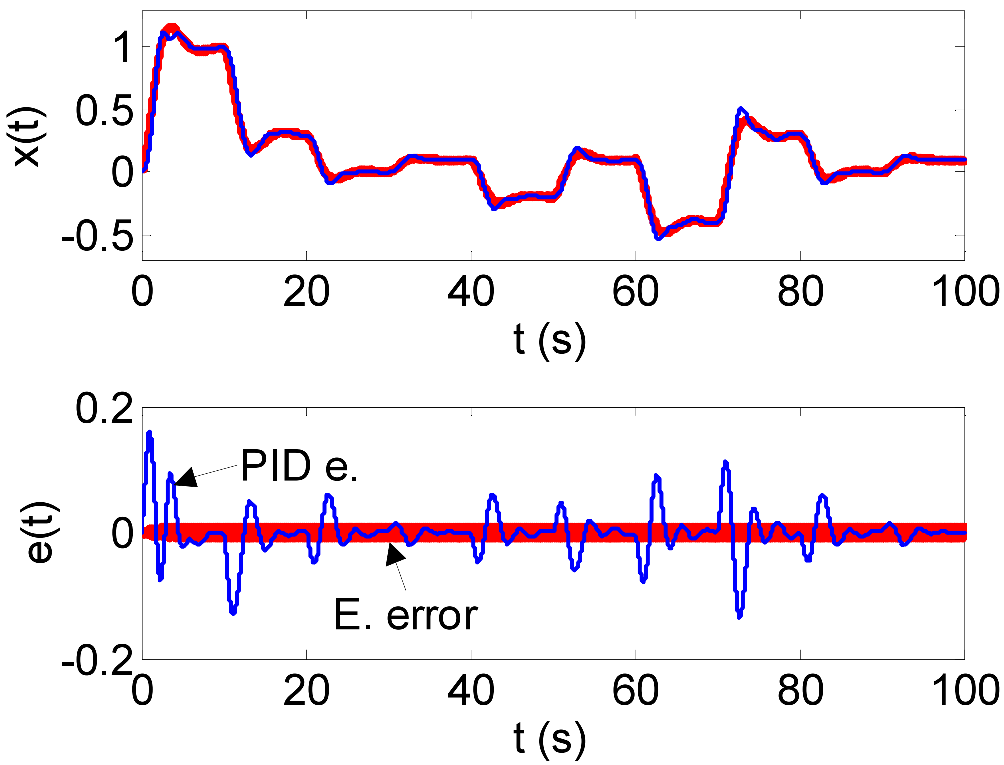
$$H = \frac{25}{S^2 + 10S + 25}$$

- kp = 7, ki = 10, kd = 1

Results (2/9)

Controlling a nonlinear plant

$$\frac{d^2x(t)}{dt^2} + \frac{dx(t)}{dt} + x(t)\left(x^2(t) - 0,2\right) = u(t)$$



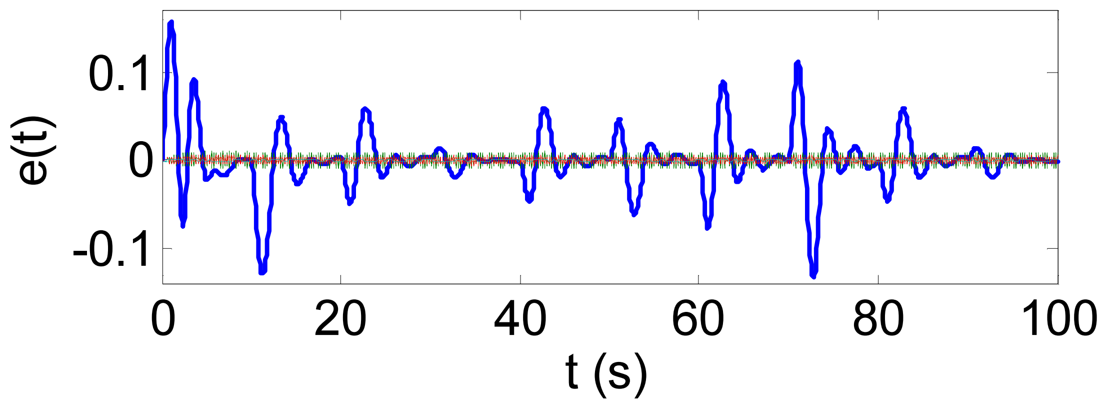
- **Reference model**:

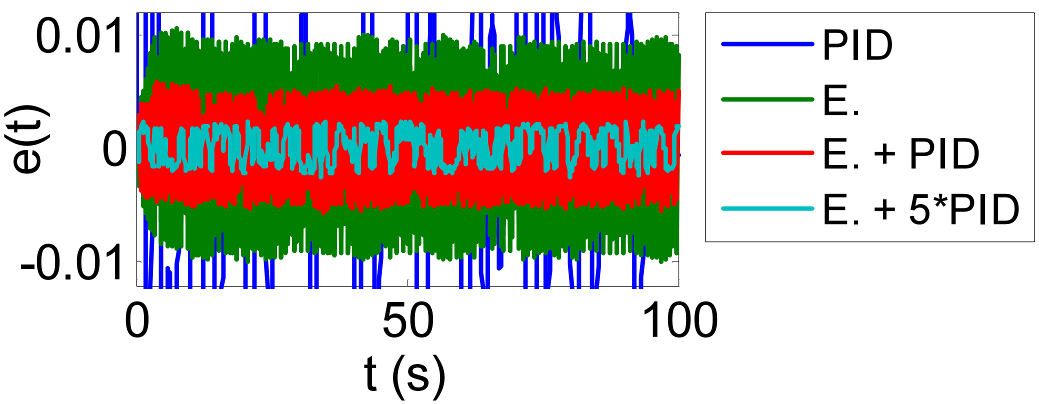
$$H = \frac{1}{S^2 + S + 1}$$

- kp = 5, ki = 5, kd = 1

Results (3/9)

Rational + Emotional

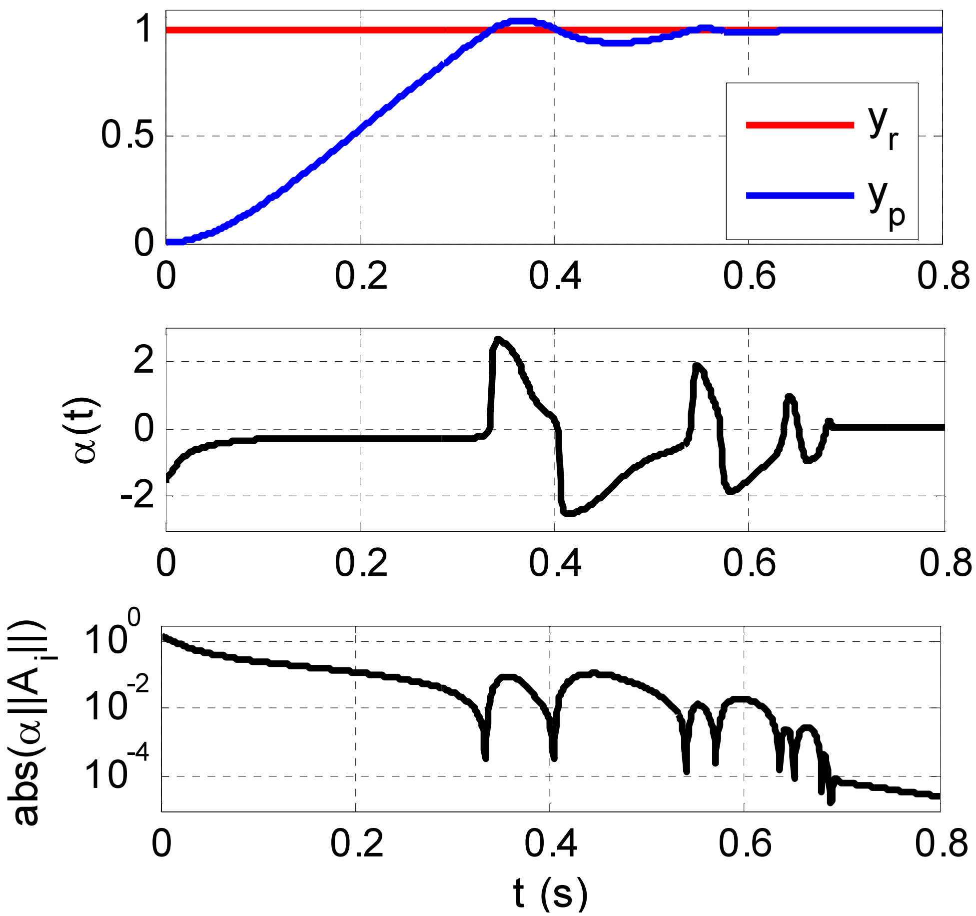




This is the result for the nonlinear plant in the previous slide

Results (4/9)

Emotional state, emotion intensity



- **Plant**:

$$H = \frac{100}{S^2 + 10S + 100}$$

- **Reference model**:

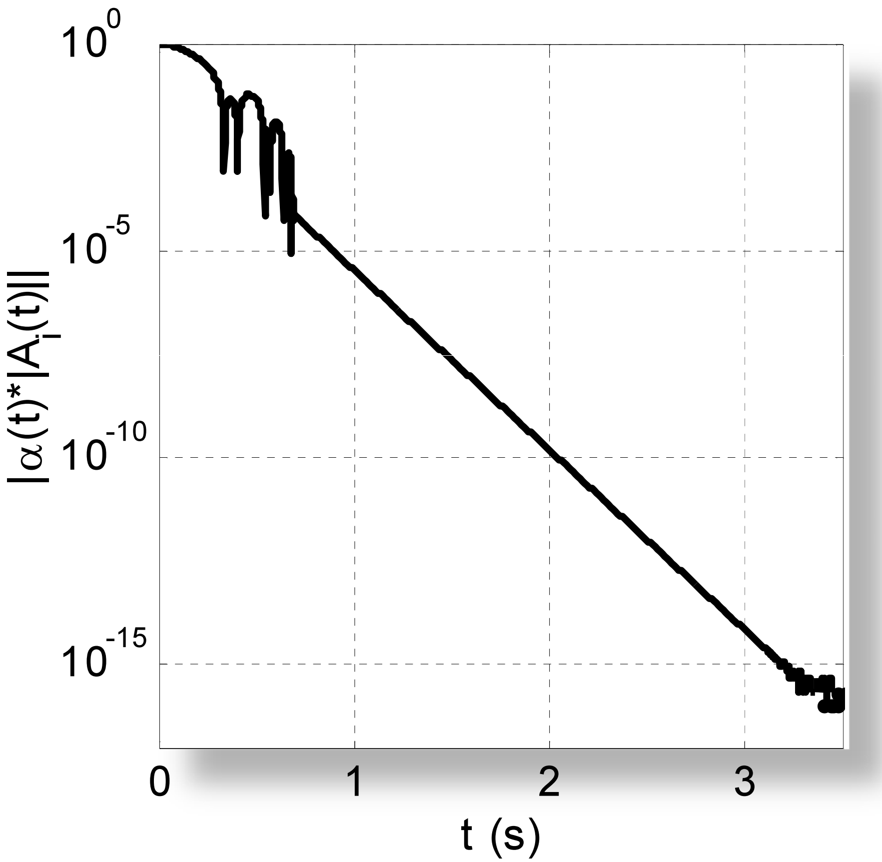
  $y_r = 1$

$Kp = 1x10^4$

$Ki = 1x10^5$

Results (5/9)

Asymptotic stability



- **Plant**:

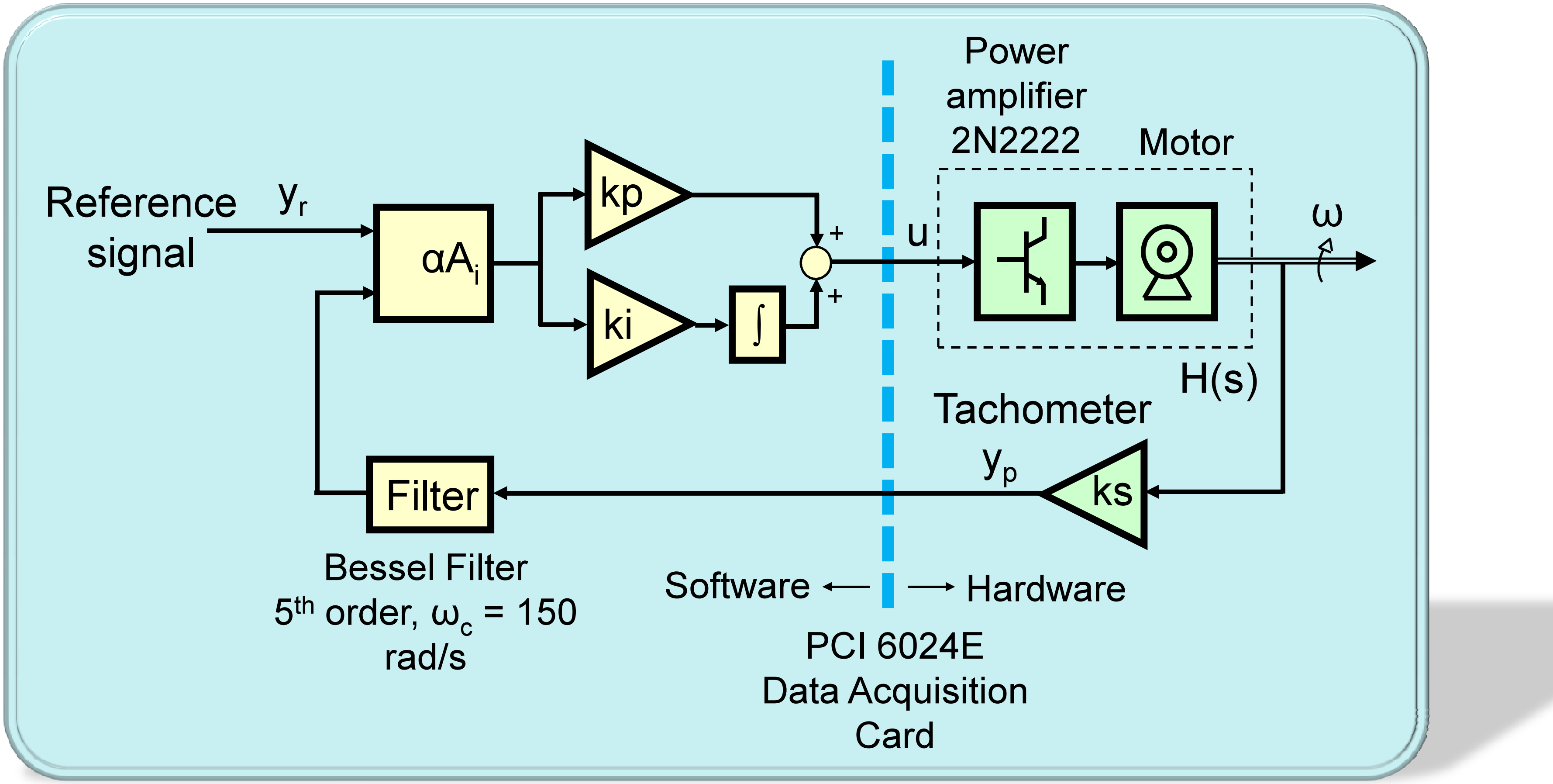
$$H = \frac{100}{S^2 + 10S + 100}$$

- **Reference model**:
  y = 1

Kp = $1\text{x}10^4$
Ki = $1\text{x}10^5$

Results (6/9)

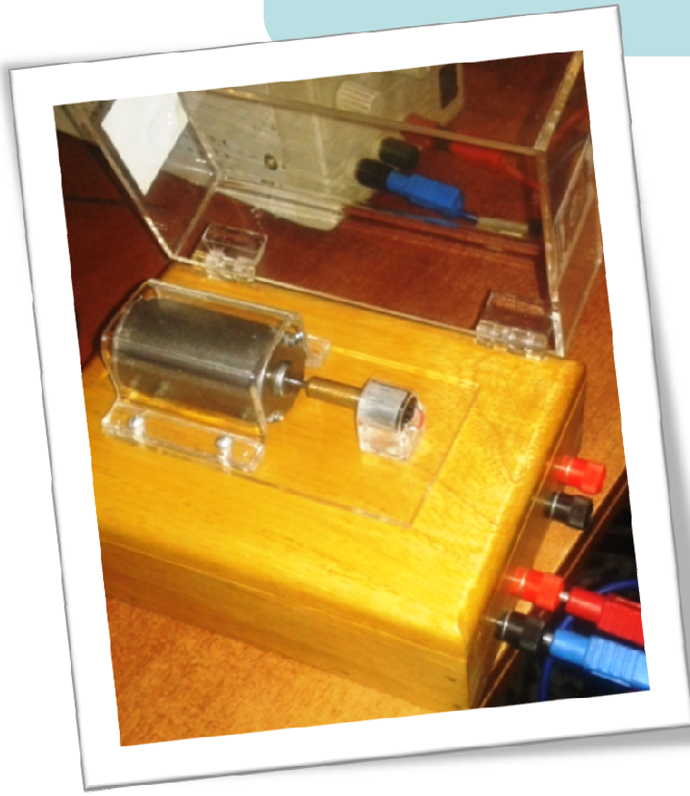
Speed control of a DC motor



Results (7/9)

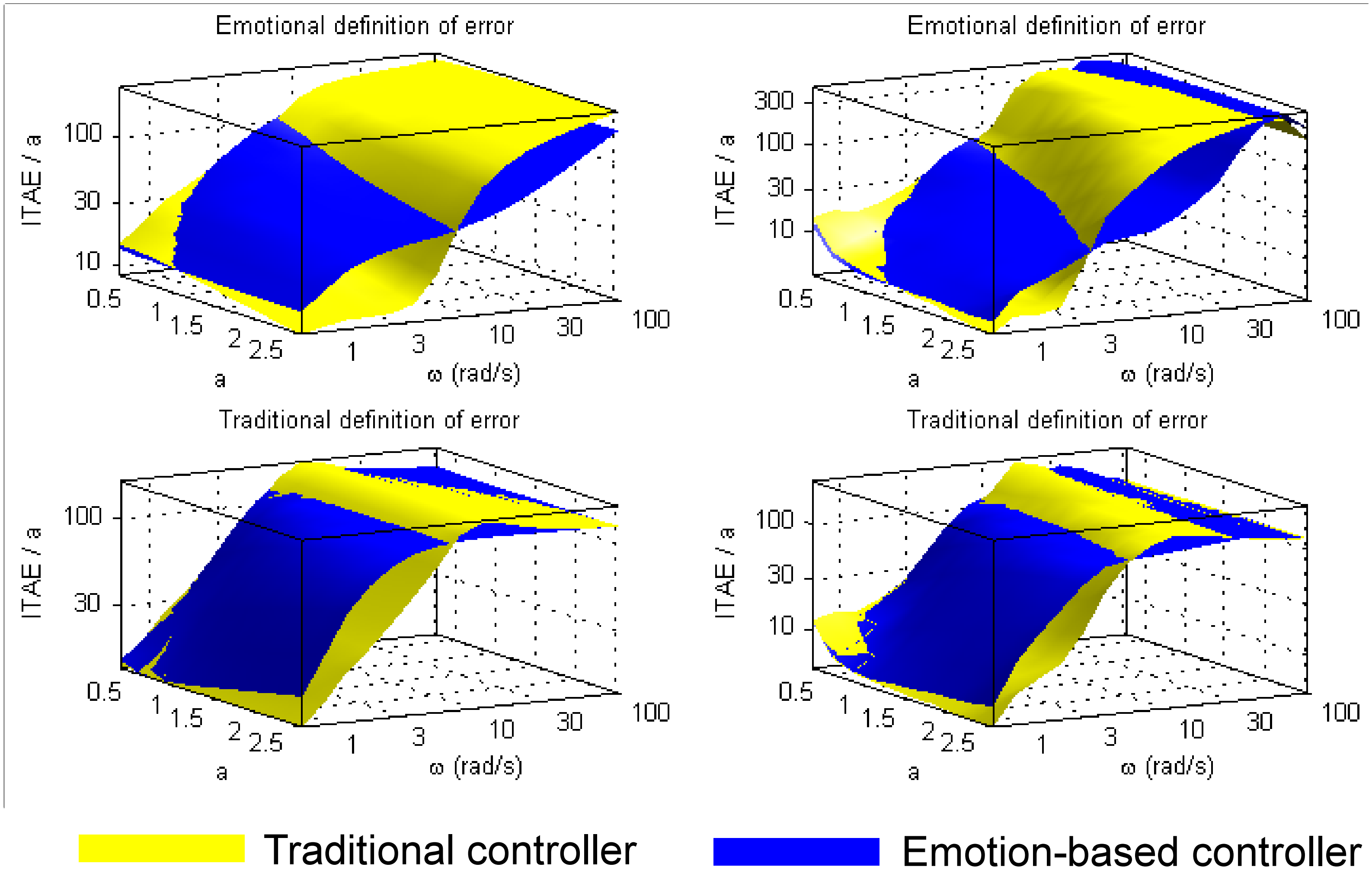
Speed control of a DC motor

- $y_r = a\sin(\omega t) + 5.5 \quad \begin{cases} 0.628 \le \omega \le 100 \\ 0.5 \le a \le 2.5 \end{cases}$
- Kp = 2, Ki = 5



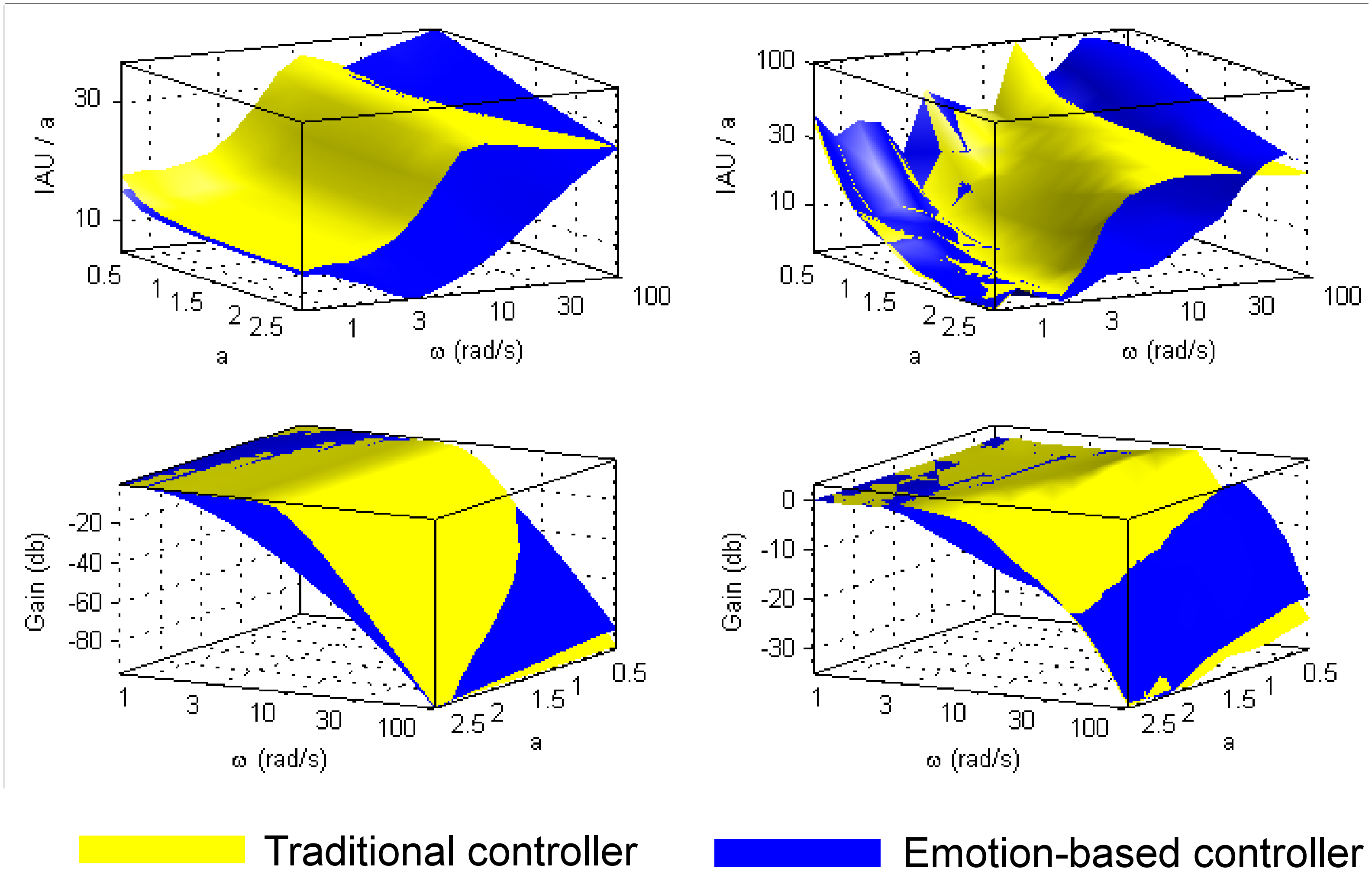
- $\text{ITAE emotional definition} = \int_0^{20} t\left|\alpha A_i\right| dt$
- $\text{ITAE traditional definition} = \int_0^{20} t\left|y_r - y_p\right| dt$
- $\text{IAU} = \int_0^{20} \left|u - 4.5\right| dt$
- $\text{Gain} = 20\log\left(\frac{\text{Aout}}{\text{Ain}}\right) \; [\text{db}]$

Results (8/9)



Emotional definition of error
ITAE / a
100
30
10
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
Emotional definition of error
ITAE / a
300
100
30
10
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
Traditional definition of error
ITAE / a
100
30
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
Traditional definition of error
ITAE / a
100
30
10
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
Traditional controller
Emotion-based controller

Results (9/9)


IAU / a
30
10
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
IAU / a
100
30
10
0.5
1
1.5
2
2.5
a
1
3
10
30
100
ω (rad/s)
Gain (db)
-20
-40
-60
-80
1
3
10
30
100
ω (rad/s)
2.5
2
1.5
1
0.5
a
Gain (db)
0
-10
-20
-30
1
3
10
30
100
ω (rad/s)
2.5
2
1.5
1
0.5
a
Traditional controller
Emotion-based controller

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Constraints

- Single input-single output systems
- Differentiable plant and reference model
- Invariant plant and reference model
- Low order dynamical systems

Conclusions (1/2)

- The introduced emotion-based control algorithm illustrates that the human brain can certainly serve as an inspiration for new control algorithms
- The Circumplex Model of Affect is adequate to propose the emotion-based control algorithm, (valence and arousal)
- Experiments in this work have demonstrated that anticipation truly serves as a bridge between cognitive concepts that embody emotions' influence on decision making in humans and the mathematical principles employed in the control of dynamical systems

Conclusions (2/2)

- Seeking to match the dynamic of two systems (reference model and plant) in an emotion-based controller results in substantial improvements in the plant's dynamic

- The emotion-based controller properly handled cycle limits by reducing their magnitude

- A reduced set of emotions can be used to control low order (linear and nonlinear) dynamical systems

Future work

- **Decision-making**: auto tuning, adaptation
- **Anticipation**: other than first order systems
- **Reference model**: learning, adaptation,…
- **Plant**: complex systems, more emotions
- **Components**: Rational + Emotional + …
- **Applications**

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Publications/Contributions

Problem

“Implementación de dos estrategias de control para la velocidad de un motor DC”, in Ingeniería e Investigación Journal, Vol. 29, Num. 2, pp. 100 – 106, 2009. A2 index*	Fuzzy logic controller to reduce the effect on nonlinearities
“Control de posición de un sistema bola y viga con actuadores magnéticos”, in Tecnura Journal, Vol. 15, Num. 30, 2011, pp. 12 – 23. B index	Effects on nonlinearities in traditional control
“Doble lazo de control para regular la posición y la velocidad en un motor de corriente directa”, in Ingeniería e Investigación Journal, Vol. 15, Num. 2, 2011, pp. 337 – 357. A2 index	Analysis of the effect of nonlinearities in traditional control

* Publication Index of Colciencias

Publications/Contributions

Problem

“*Diseño de controladores de tipo proporcional integral derivativo (PID) y difuso para la posición de un motor de corriente continua*”, in Ingeniería e Investigación Journal, Vol. 14, Num. 1, 2010, pp. 137 – 160. B index	Plant to make experimental validation
“*Implementación de nuerocontroladores en línea. Tres configuraciones tres plantas*”, in Ingeniería y Universidad Journal, Vol. 16, Num. 2, pp. 163 – 182, 2012, A2 index	Application of an artificial neural network to reduce the effects of nonlinearities

Reference model

“Robot path optimization based on a reference model and sigmoid functions”, in International Journal of Advanced Robotic Systems, under review, IF = 0.81, A2 index	Nonlinear reference model application
“Green Approaches to Process Control in Thermal Rooms” in Control and applications CA2011, Vancouver, BC, Canada. Jun. 1 – 3, 2011	The reference model concept was introduced

Publications/Contributions

Anticipation

"Period estimation for reconstruction of (quasi-) periodic signals", in International Journal of Adaptive Control and Signal Processing, 2014, IF = 1.21, A2 index	An algorithm to estimate frequency of a discrete signal
"Medición del sentido de giro, velocidad y posición angular de un eje mediante encoders", in Respuestas Journal, Universidad Francisco de Paula Santander, Vol. 15 Num.1, pp. 33 – 42, 2010. C index	An algorithm to measure the rate of change of a signal
"Reconstruction of Periodic Signals Using Neural Networks", in Tecnura Journal, Num. 37, 2013, A2 index	A procedure to estimate the Fourier coefficients using a neural network
"Period approximation", in Research day, University of Memphis, Computer Science Department, best paper presentation, 2012	An algorithm to approximate the period of a periodic function by minimizing the mean squared error

Publications/Contributions

Anticipation

"Two algorithms to Estimate the period of a Discrete Signal" in Ingeniería e Investigación Journal, in review, A1 index	Two algorithms to approximate the period of a periodic signal
"Implementación en dsPIC de un algoritmo óptimo para la estimación de velocidad de giro", In Iteckne, in review, B index	Experimental validation of the optimal algorithm to estimate rate of change
"An optimal algorithm for estimating angular speed using incremental encoders", Ingeniería e Investigación, pp. 56-62, 2013, A1 index	A new algorithm to approximate the rate of change of a signal

Publications/Contributions

Computational models of emotion

"Control basado en emociones, una revisión" in Convención internacional de ingeniería in Cuba – CIIC, Jun. 4 – 6, 2008	State of the art
"Control basado en emociones - una revisión", in Avances en Sistemas e Informática Journal, Vol. 7, Num. 2, 2010, pp. 27 – 40. C index	State of the art
"Modelo circumplejo del afecto aplicado al control de sistemas dinámicos", in Respuestas Journal, year 14, Num. 1, 2009, pp. 5 – 15. C index	Circumplex model of affect as based for the emotion model

Publications/Contributions

Control architecture

"Algoritmo para la Toma de Decisiones Basado en las Emociones Humanas Aplicado al Control de Sistemas Dinámicos", in sdsc09 Doctoral Symposium, Jul. 24, 2009	Definition of the proposed controller
"Definition of emotional states for dynamical systems", in Visión electrónica Journal, year 5, Num. 2, 2011, pp. 4 – 18. C index	Definition of a set of emotional states for dynamical systems
"Definition of an emotion-based controller for dynamical systems", in Tecnura Journal, Num. 33, 2012, A2 index	The control architecture
Emotion-based controller, principles and applications Draft	

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