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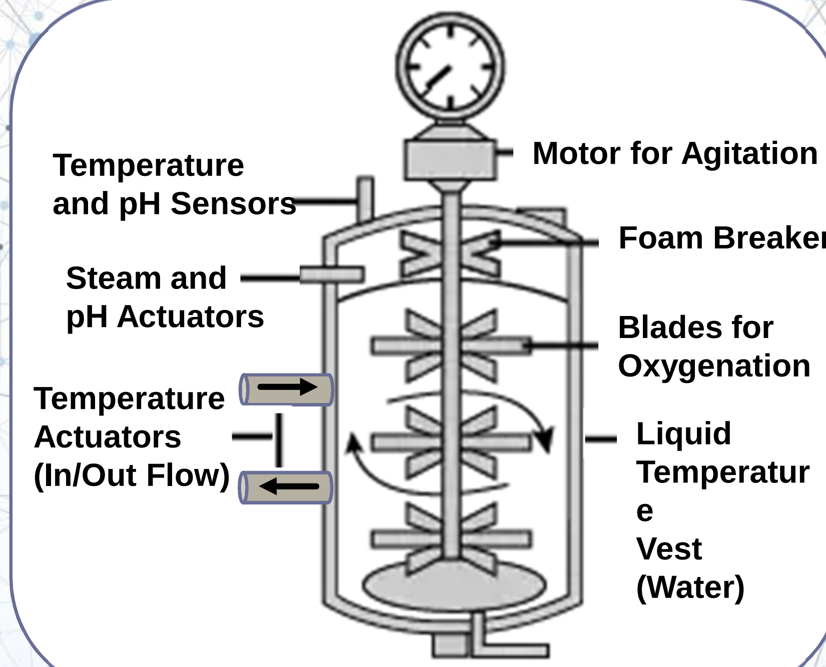
Customized Adaptative Neuro-Fuzzy Approach to pH Control on a Stirred Tank Bioreactor

Eng. Fernando A. Hernández Gobertti, Eng. Carlos H. Cigliutti Barilari

Dr. Eng. André Luiz Fonseca De Oliveira



SYSTEM PRESENTATION / Presentación del Sistema

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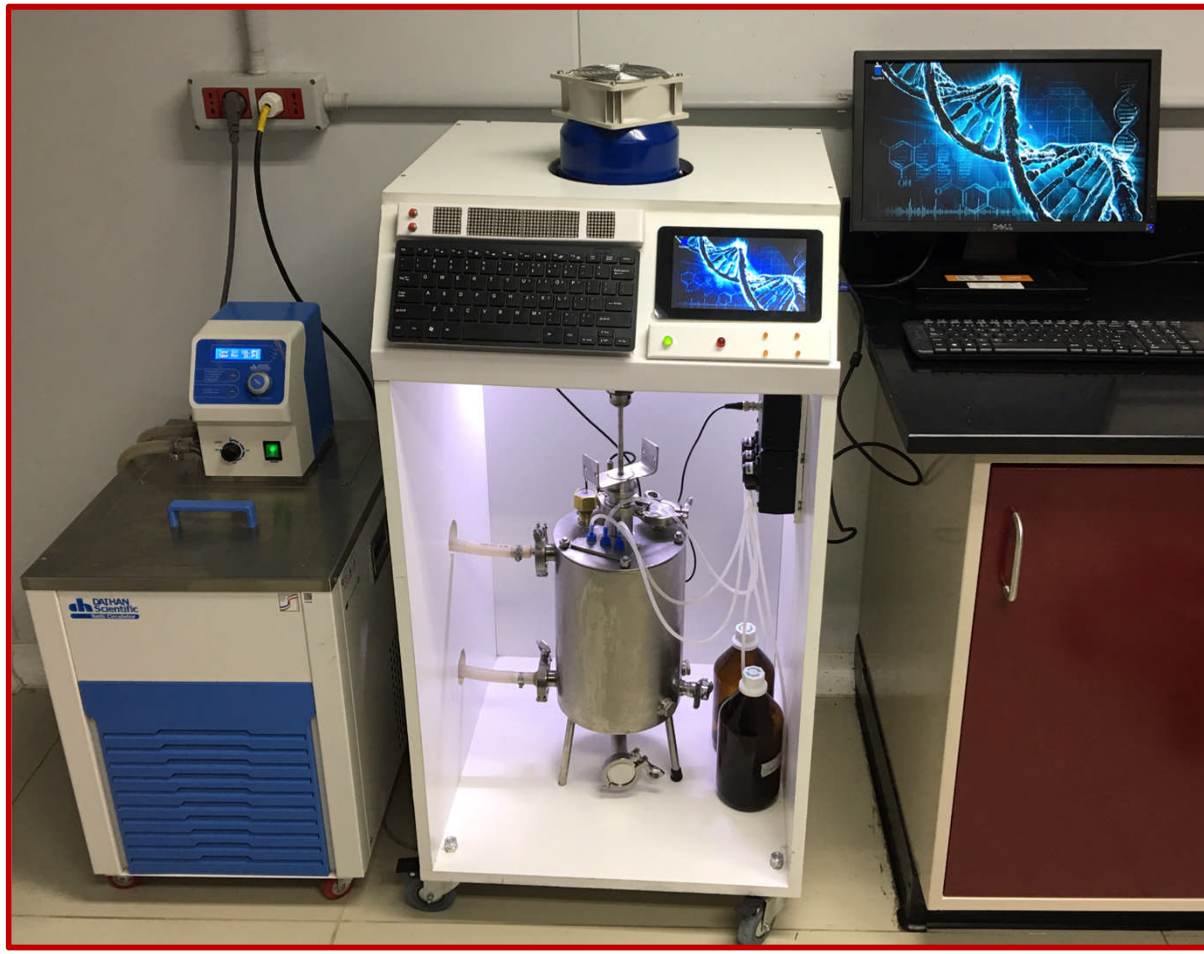
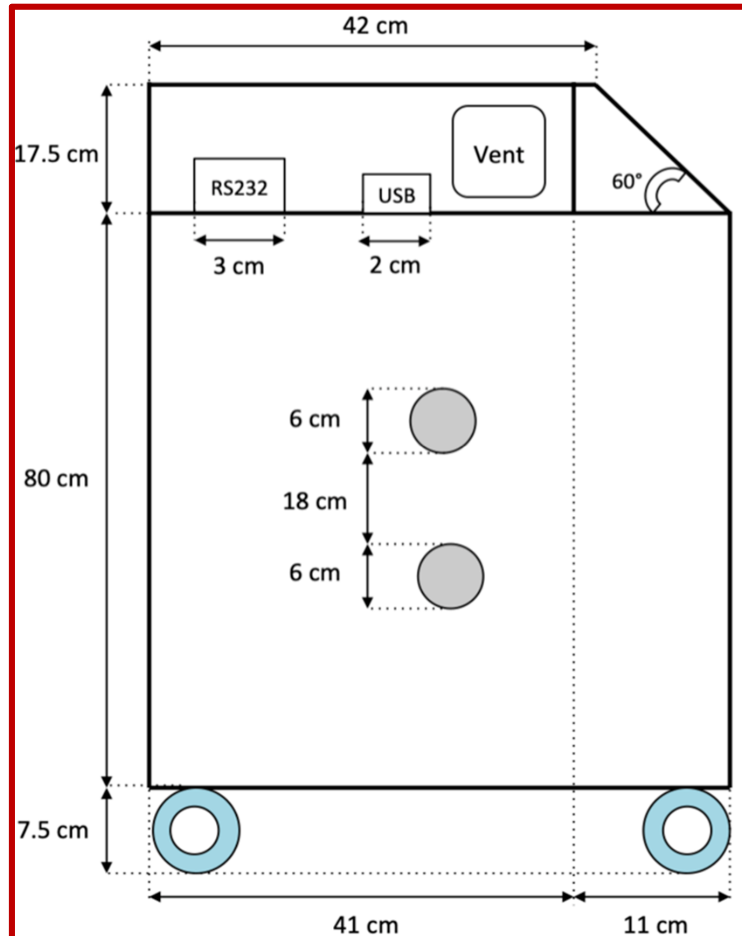


Overview of **bioreactor system equipment** in full operation.



Sideview diagram of **bioreactor system furniture.**

Bioreactor System Description and Visualization

DEVICES ORGANIZATION / Orden de Componentes

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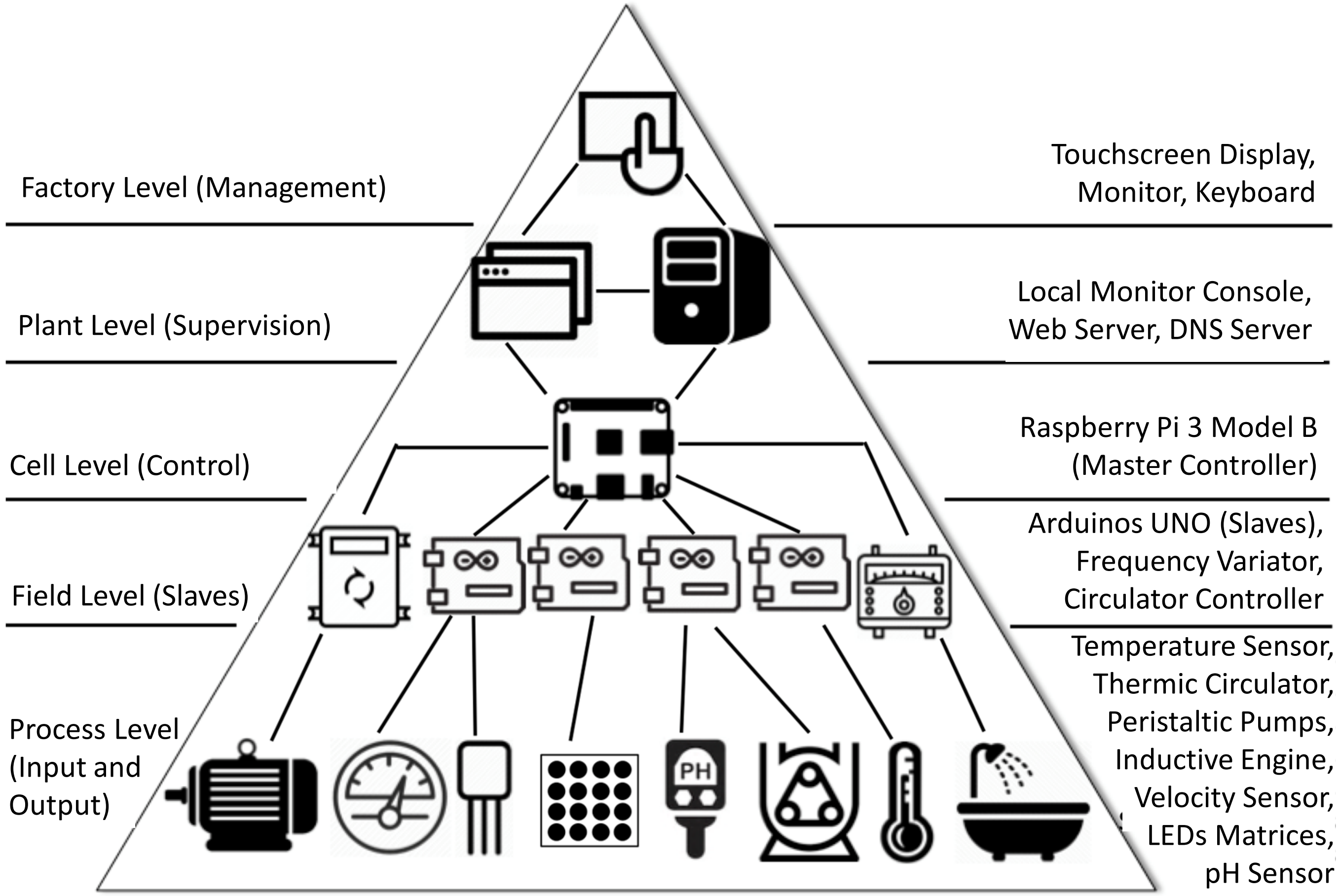
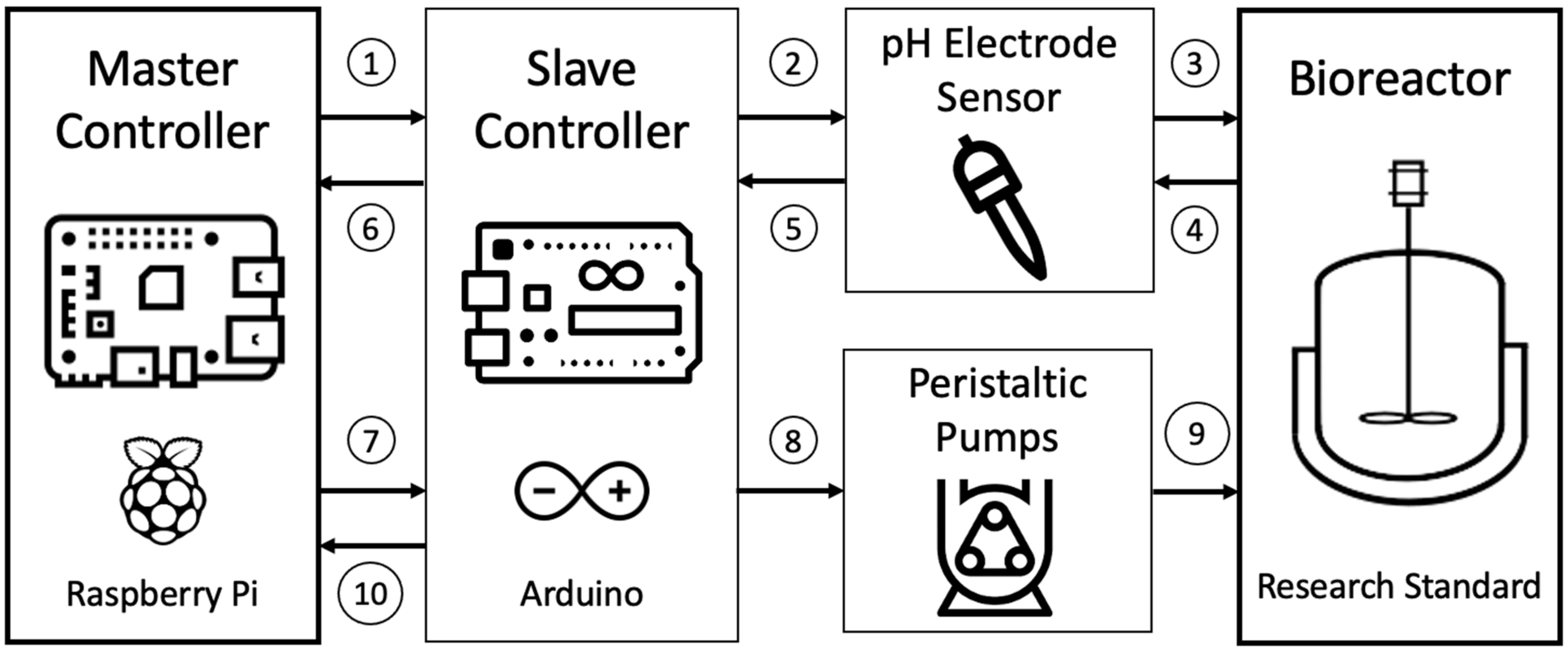


- Centralized Industrial Control **Architecture**.
- Master-Slave Relationships between **Devices**.
- Pre-existing, Custom and Acquired **Equipment**.
- Affordable and Easy-to-use **Peripherals**.
- **Favorable** to Scalability and Maintenance.
- Efficient Academic and Commercial **Usage**.

Global Components and Diagramming



- pH Peripherals
- Acid/Base Pumps
- Process Sequencing
- Industrial Protocols
- Pulse Width Modulation
- Drops Capacities

pH-related Components and Sequencing

PERIPHERALS EXAMINATION / Exámen de Periféricos

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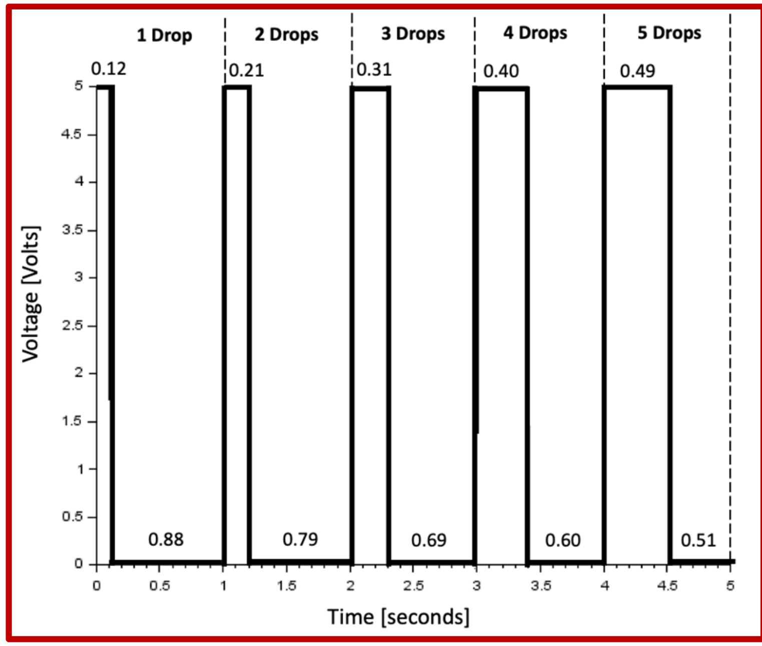
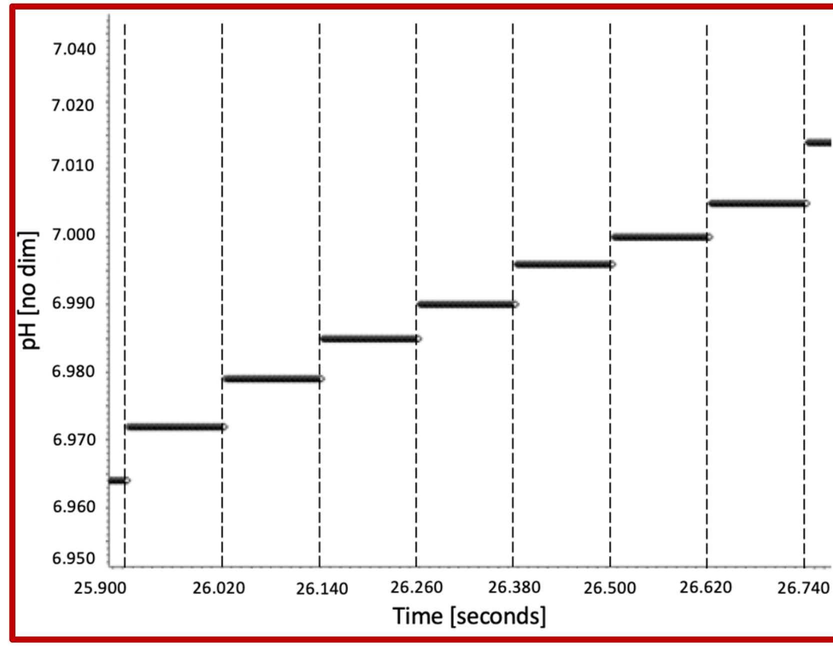


Signaling to actuators using **PWM.**

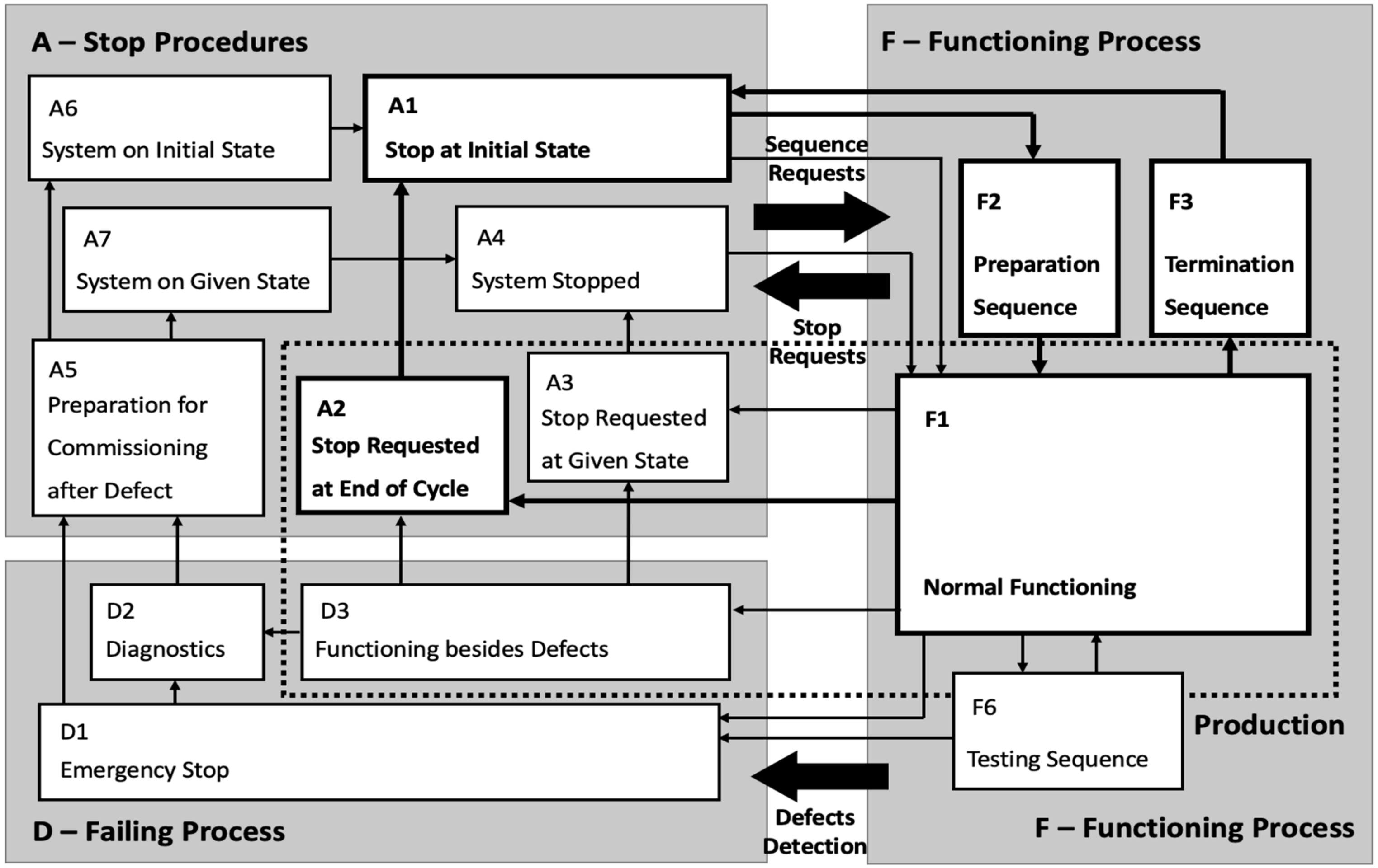
- Actuators Interactions
- 1 to 5 Drops per Burst
- Independent Circuits
- Non-Inertial Behavior
- Real-time cycles variations
- 7 mL per 100 Drops



Incremental periodic **pH variation.**

Burst	Delay	Burst	Delay	Burst	Delay	Burst	Delay	Burst	Delay
1 sec	0.5 sec	1 sec	0.5 sec	1 sec	0.5 sec	1 sec	0.5 sec	1 sec	0.5 sec

Cycles Management and Pulse Width Modulation

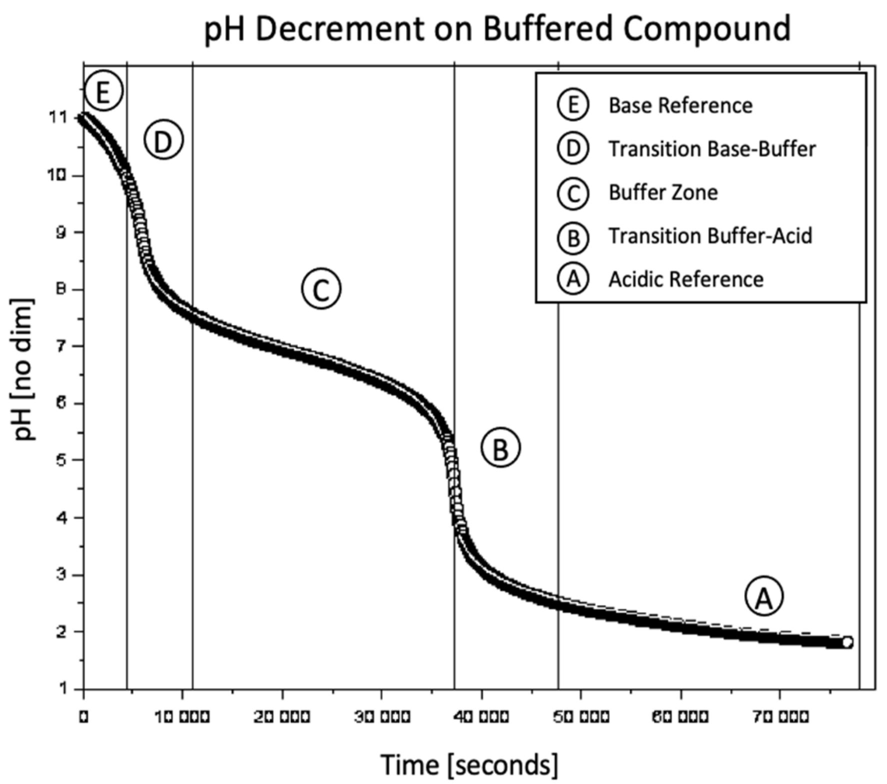


- Long Periods of Continuous Functioning
- Running Time Occurrences (Stops, Fails)
- Predominant Defects: Measurement,

Communication, Malfunctions

- Bidirectional Master-Slave Interactions
- Unidirectional Peripherals Instructions

GEMMA Framework Adaptation for Automation

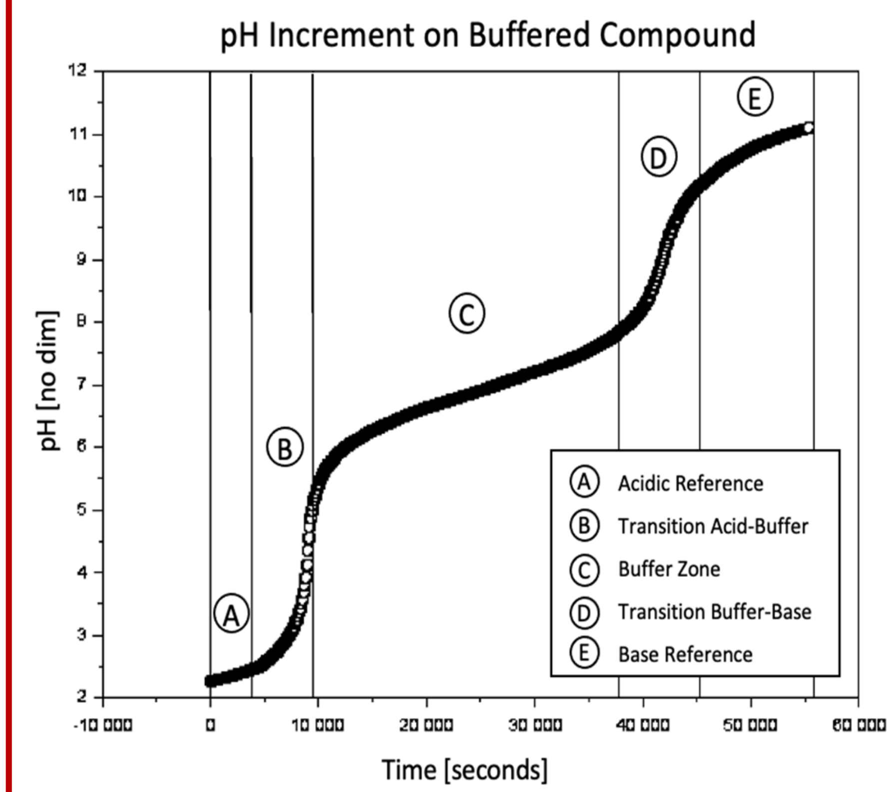


Compound: Streptococcus Thermophilus; **Buffer:** KH_2PO_4

Start: pH 11.1; **End:** pH 1.8; **Duration:** 77.000 sec

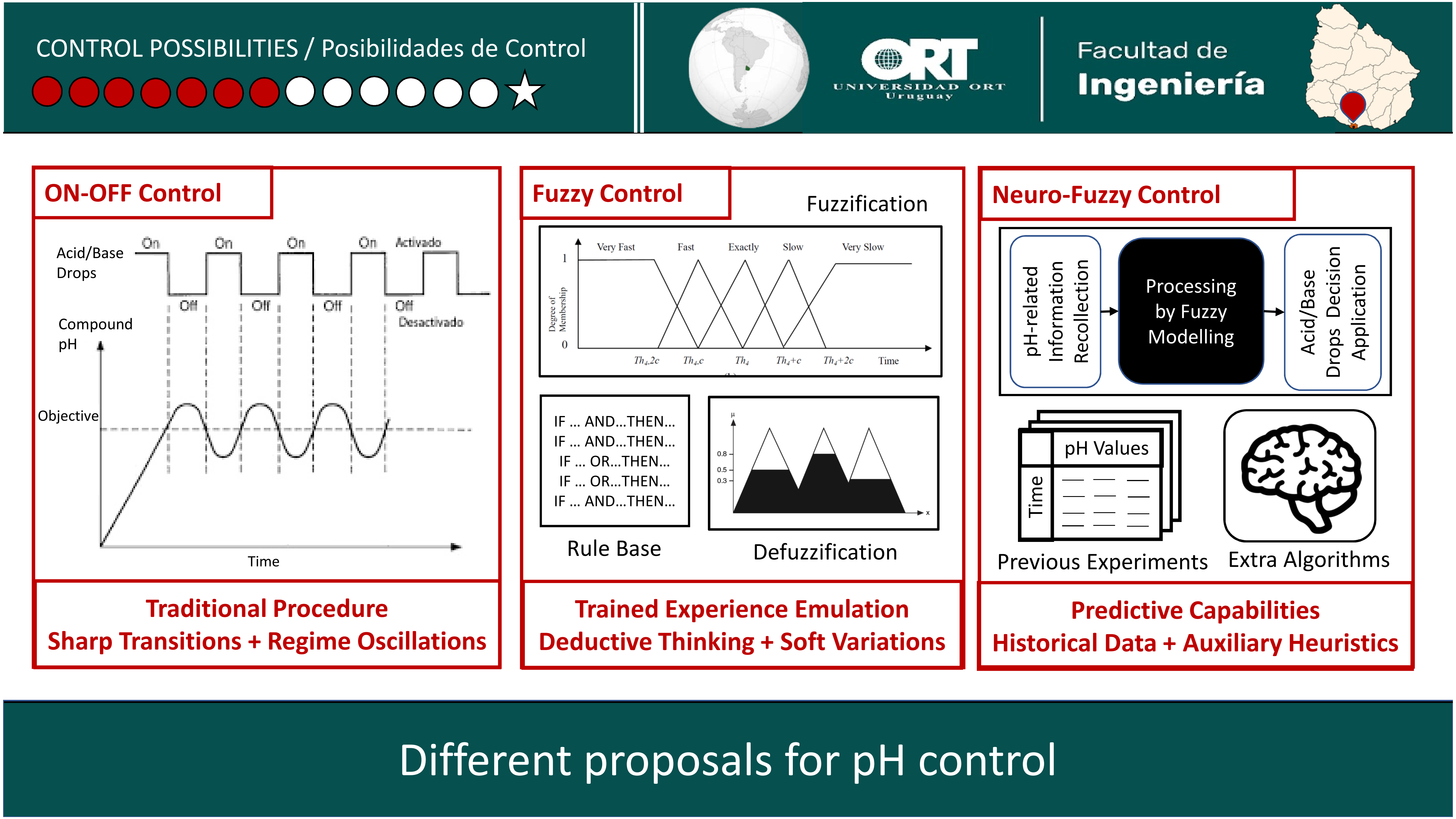
Compound: Streptococcus Thermophilus; **Buffer:** KH_2PO_4

Start: pH 2.3; **End:** pH 11.2; **Duration:** 56.000 sec



- General Observations on Buffered Solutions Behavior
- Immediate Effect per Drop
- Limited Working Range
- Limited Solution Capacities
- Cycles Management (6-10 s)
- Distinction by pH Steepness

Zones Distinction on pH Variations



CONTROL POSSIBILITIES / Posibilidades de Control
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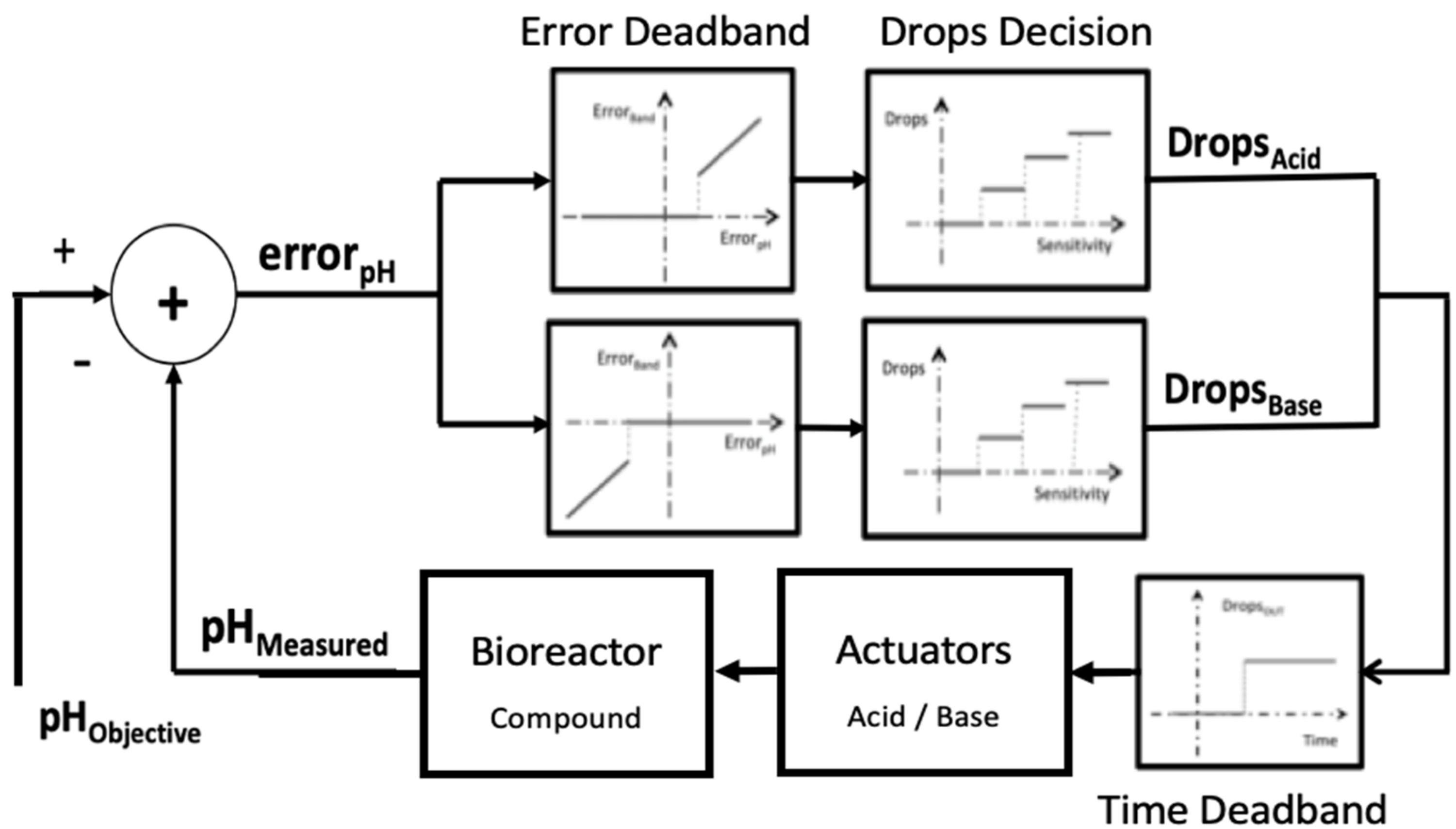
ON-OFF Control
Acid/Base Drops
On
Off
Activado
Desactivado
Compound pH
Objective
Time
Traditional Procedure
Sharp Transitions + Regime Oscillations
Fuzzy Control
Fuzzification
Very Fast
Fast
Exactly
Slow
Very Slow
Degree of Membership
Time
IF ... AND...THEN...
IF ... AND...THEN...
IF ... OR...THEN...
IF ... OR...THEN...
IF ... AND...THEN...
Rule Base
Defuzzification
Trained Experience Emulation
Deductive Thinking + Soft Variations
Neuro-Fuzzy Control
pH-related Information Recollection
Processing by Fuzzy Modelling
Acid/Base Drops Decision Application
pH Values
Time
Previous Experiments
Extra Algorithms
Predictive Capabilities
Historical Data + Auxiliary Heuristics
Different proposals for pH control



- **Input:** pH Objective, pH Measured
- Decisions over pH Sensibilities and Error
- pH Deadband fixed at 0.05 difference
- Time Deadband per 6-10 seconds cycles
- Similar Procedures for Acid and Base
- **Output:** Drops Amount to Expulse

Specification of Sensibility-based ON-OFF Control

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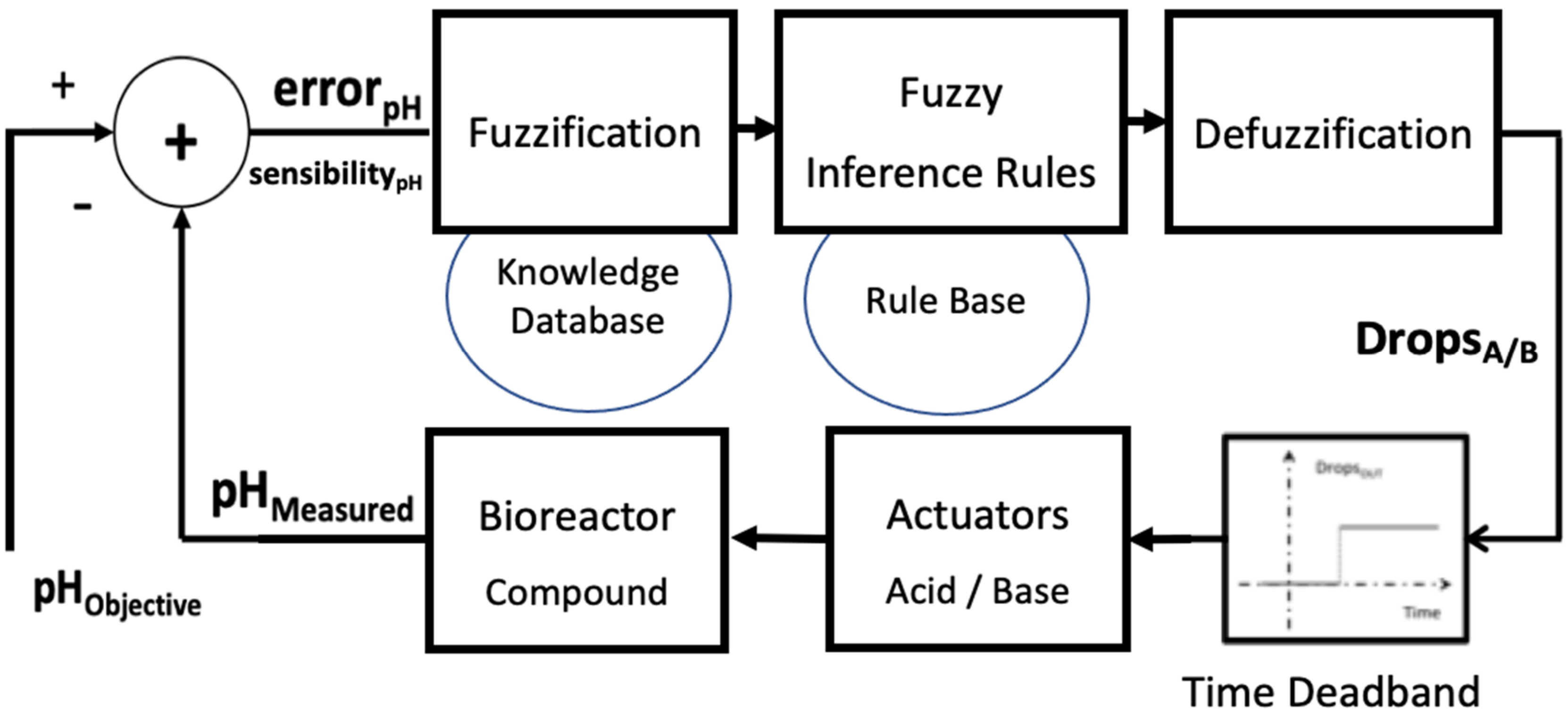
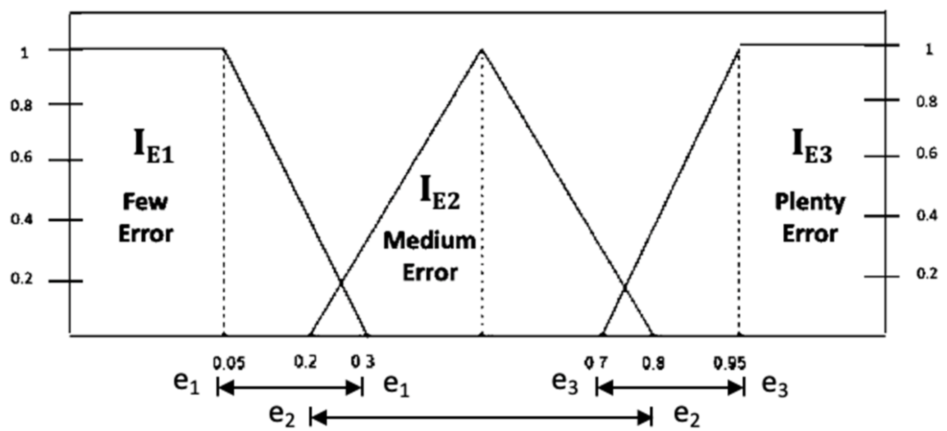
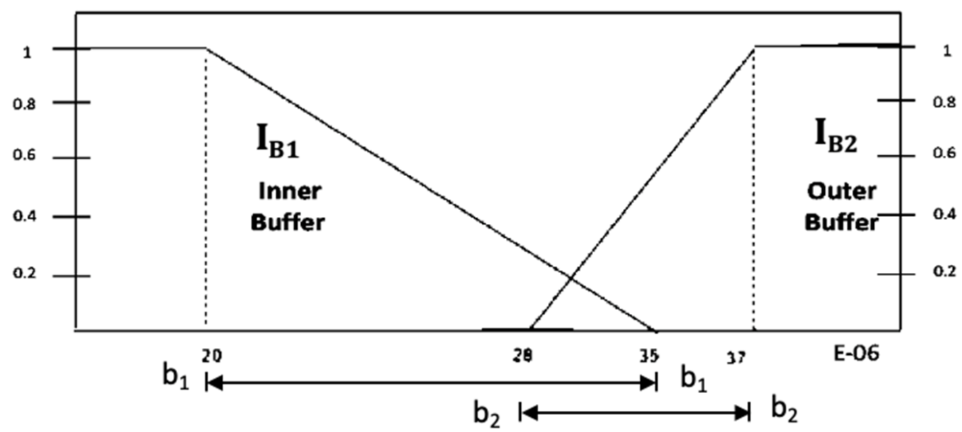


- **Input:** pH Objective, Measured
- **Memberships:** pH Sensibilities, Error
- Globally Softer System Response
- Time Deadband per 6-10 sec cycles
- Similar Procedures for Acid and Base
- **Output:** Drops Amount to Expulse

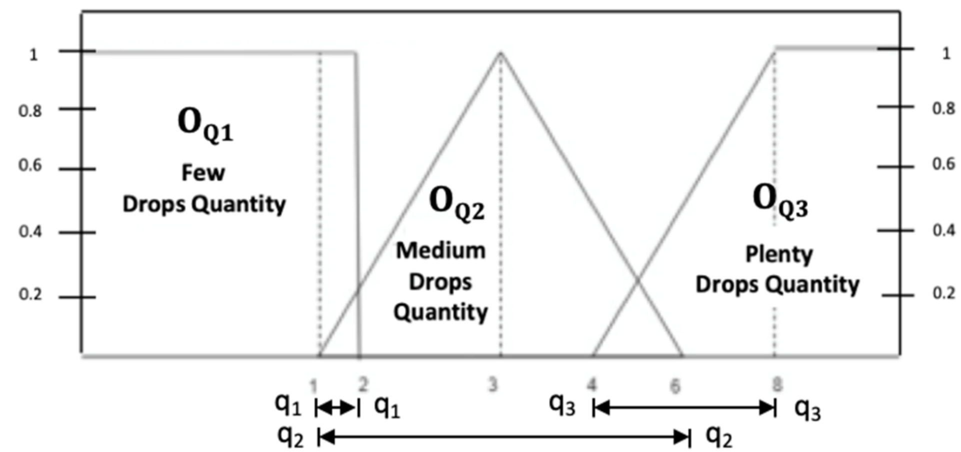
Specification of Proposed Fuzzy-based Control

Input Membership Functions:





Output Membership Functions:



The conditional rule base is described as follows:

- $\mathrm{IF}[(I_E = I_{E1} \wedge I_B = I_{B2})] \Rightarrow O_{Q1} = O_{Q1}^{acid} \vee O_{Q1}^{base}$
- $\mathrm{IF}[(I_E = I_{E1} \wedge I_B = I_{B1})] \Rightarrow O_{Q2} = O_{Q2}^{acid} \vee O_{Q2}^{base}$
- $\mathrm{IF}[(I_E = I_{E2} \wedge I_B = I_{B2})] \Rightarrow O_{Q1} = O_{Q1}^{acid} \vee O_{Q1}^{base}$
- $\mathrm{IF}[(I_E = I_{E2} \wedge I_B = I_{B1})] \Rightarrow O_{Q2} = O_{Q2}^{acid} \vee O_{Q2}^{base}$
- $\mathrm{IF}[(I_E = I_{E3} \wedge I_B = I_{B2})] \Rightarrow O_{Q2} = O_{Q2}^{acid} \vee O_{Q2}^{base}$
- $\mathrm{IF}[(I_E = I_{E3} \wedge I_B = I_{B1})] \Rightarrow O_{Q3} = O_{Q3}^{acid} \vee O_{Q3}^{base}$

Fuzzy Membership Functions and Rules Base

NEURO-FUZZY CONTROL + GENETIC ALGORITHM

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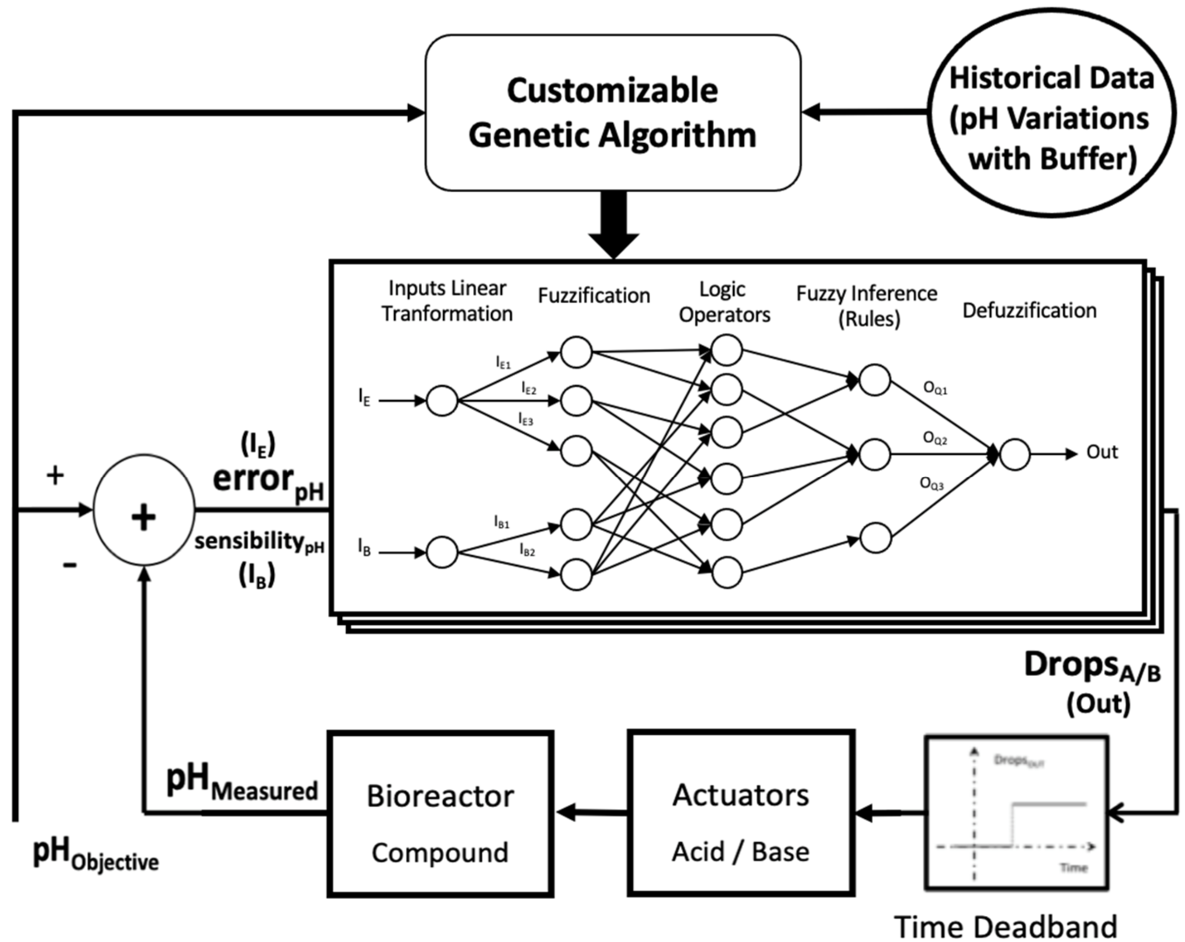

$$\begin{pmatrix} e_1^t & e_2^t & e_3^t \end{pmatrix} = \begin{pmatrix} \alpha_I & \alpha_{II} & \alpha_{III} \end{pmatrix} \begin{pmatrix} e_1^{t-1} & e_2^{t-1} & e_3^{t-1} \\ e_1^{t-2} & e_2^{t-2} & e_3^{t-2} \\ e_1^{t-3} & e_2^{t-3} & e_3^{t-3} \end{pmatrix}$$

$$\begin{pmatrix} b_1^t & b_2^t \end{pmatrix} = \begin{pmatrix} \beta_I & \beta_{II} \end{pmatrix} \begin{pmatrix} b_1^{t-1} & b_2^{t-1} & b_3^{t-1} \\ b_1^{t-2} & b_2^{t-2} & b_3^{t-2} \end{pmatrix}$$

$$\begin{pmatrix} q_1^t & q_2^t & q_3^t \end{pmatrix} = \begin{pmatrix} \gamma_I & \gamma_{II} & \gamma_{III} \end{pmatrix} \begin{pmatrix} q_1^{t-1} & q_2^{t-1} & q_3^{t-1} \\ q_1^{t-2} & q_2^{t-2} & q_3^{t-2} \\ q_1^{t-3} & q_2^{t-3} & q_3^{t-3} \end{pmatrix}$$

- **Customization Attributes:**
  - Proportional Parameters ($\{\alpha_i, \beta_j, \gamma_k\}$)
  - Parenting Selection ($\{e_i^{t-n}, b_j^{t-m}, q_k^{t-p}\}$)

Specification of Customizable Neuro-Fuzzy Control

RESULTS COMPARISON/ Comparación de Resultados

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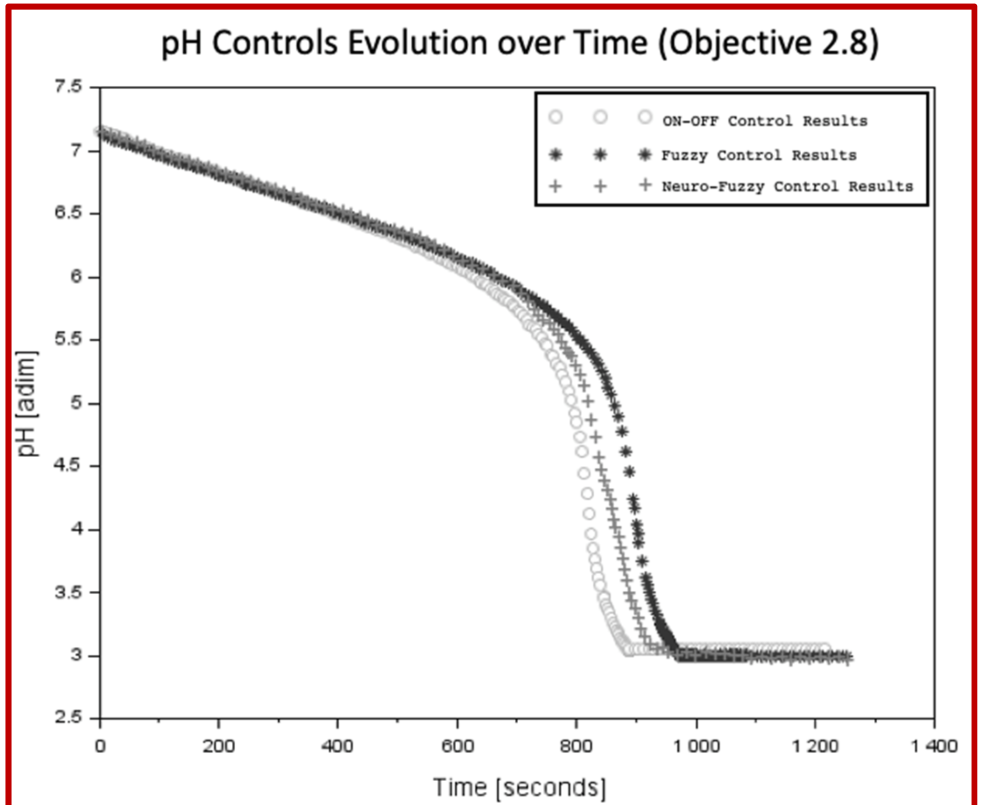

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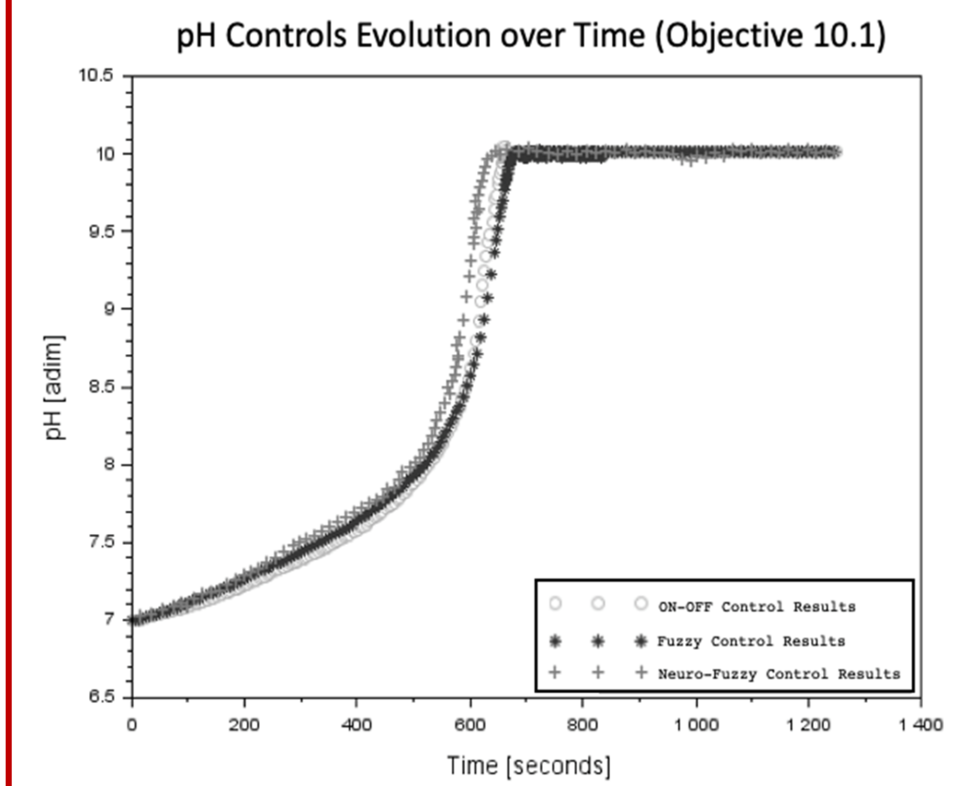

- Multiple Repetitions
- All controls: Less than pH 0.1 stationary error
- Precision at Regime
- Transition Time
- Noisy Data Robustness
- Adaptability Changes
- Objective Divergences

System Response to pH Controls at Different Setpoints

FURTHER RESEARCH / Investigación Futura

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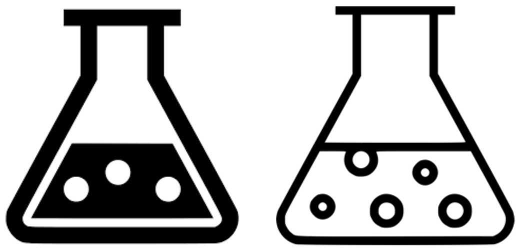
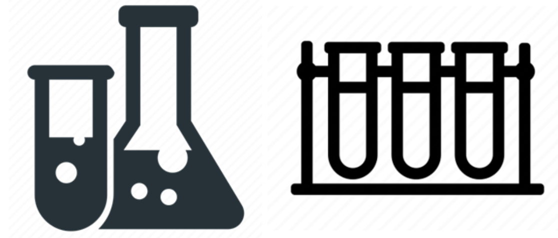
Actuator Selection



- Standard Solutions (70%):
  - HCl (Acid) – pH 1.8
  - NaOH (Base) – pH 11.6

Testing with Different Actuators (Concentration and Composition)

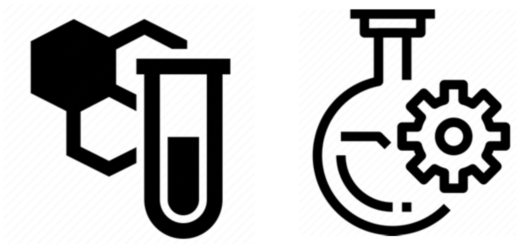
Buffer Usage



- Usual Buffer Solutions:
  - KH_2PO_4
  - $C_2H_4O_2$
  - $C_2H_3NaO_2$
  - $Ca_3(BO_3)_2$

Testing with Different Buffers (Concentration and Composition)

Microorganisms Definition



- Traditional in Biotechnology:
  - Streptococcus Thermophilus
  - Escherichia Coli
  - Myxococcus Xanthus

Application to Different Microorganisms (Composition)

Related Future Research Possibilities and Opportunities

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Eng. Fernando A. Hernández

fhernandez@ieee.org

Eng. Carlos H. Cigliutti

cgcigliutti@gmail.com

Dr. Eng. André L. Fonseca

fonseca@fi365.ort.edu.uy

Thank you for your attention. Questions?