



Analysis of Case Studies in Engineering Systems Using Artificial Neural Networks

2nd International Workshop on Automation

Puebla City, Puebla

Speaker:

Jesús López Gómez

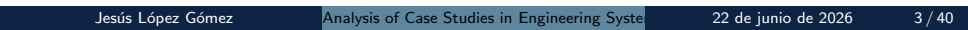
Professor Research

Juárez Autonomous University of Tabasco, Mexico

22 de junio de 2026

UNIVERSIDAD JUÁREZ AUTÓNOMA DE TABASCO





Research Group and Collaborations

LGAC: HUMAN-COMPUTER INTERACTION, ROBOTICS, AND INTELLIGENT CONTROL

Benemérita Universidad Autónoma de Puebla:

*Facultad de Ciencias de la Electrónica,
Master of Science of the Electronics, Option in Automation*

- Sergio Vergara Limon, PhD. Level 2 - SNII.
- María Aurora D. Vargas Treviño, PhD. Level 2 - SNII.
- Amparo Dora Palomino Merino, PhD. Level 1 - SNII
- Luis Ernesto Valencia, PhD. Level C - SNII.
- Yoltic Faustino Gutiérrez Tellez, MsC. Student.
- Luis Francisco de la Rosa Pineda, MsC.
- Abril Donahi Castro Sánchez, MsC.
- Luis Arturo Alcantar, MsC.

*Facultad de Ciencias de la Computación,
Doctorate in Language and Knowledge Engineering*

- Carlos Carreón Díaz de León, PhD. Level C - SNII.
- Daniel González Arriaga, PhD. Level C - SNII.
- Margarita García López, PhD. Student.
- Michelle Guerra Marín, PhD. Student.
- Juan Francisco Pintor Michimani, PhD. Student.
- Gabriela Aquino González, PhD. Student.
- María Fernanda Arámburo Castell, PhD. Student.

LGAC: ELECTRICAL AND ELECTRONIC SYSTEMS

Universidad Juarez Autónoma de Tabasco:

División Académica de Ingeniería y Arquitectura,

- Fermín Martínez Solís, PhD. Level 1 - SNII.
- Reymundo Ramírez Betancourt PhD. Level 1 - SNII.

*Centro de Investigación de Ciencia y Tecnología Aplicada
de Tabasco (C.I.C.T.A.T.)*

Semiconductor Laboratory:

- Dr. Erik Ramírez Morales, PhD. Level 2 - SNII.
- Carlos Emilio Marquez García, MsC.
- Rodrigo Alamilla Vásquez, MsC.

LGAC: ENERGY, PHOTOCATALYTIC, AND MECHANICAL SYSTEMS BASED ON NANOSTRUCTURED SURFACES

Surface Engineering and Renewable Energy Laboratory:

- Germán Pérez Hernández, PhD. Level 2 - SNII.
- Rafael Torres Ricárdez, PhD. Level 1 - SNII.
- Bryan Leonardo Pérez Escobar, PhD. Level 1 - SNII.

- Students from other institutions have been hosted for national and state-level stay.
- Scientific summer programs.
- (Social Impact) – 1st place nationally at the 2026 Mexican Science and Engineering Fair (FEMECI), organized by REDNACECYT. Project: "Haptic system for converting digital text to Braille as assistive technology"
- (Entrepreneurship and Social Impact) – 1st place at the state level in the T-IDEA 2026 Hackathon, held as part of the forum organized by the Tabasco Delegation of COPARMEX, AgroTech Category – Project: "Agro Cacao Tech"
- 1st place at the state level in the Cup RoboFut Tabasco 2026.
- Currently, various social and environmental impact projects are underway to address real state and regional problems, with students collaborating in the laboratory.

Conference Title:

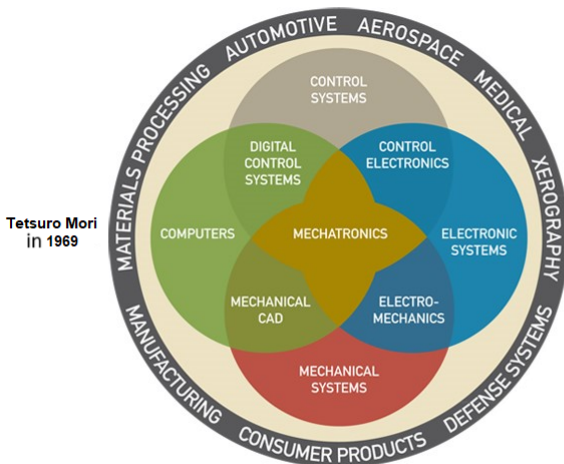
Analysis of Case Studies in Engineering Systems Using Artificial Neural Networks

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- 2 Case Study in Robotic System Modeling
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Introduction

Mechatronics and its applications



Model-based design is the key to solving the problems we face.
Modeling is the language of modern engineering.

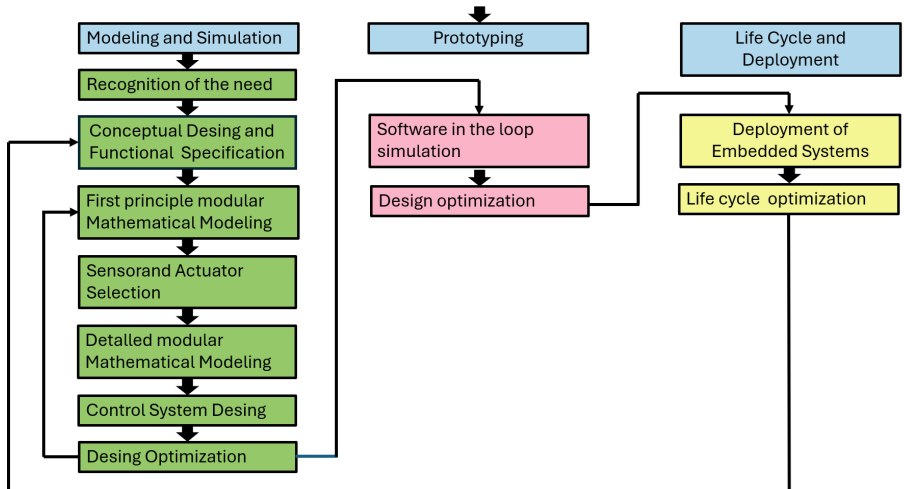
Dr. Keven Craig, Marquette University.

Precision mechatronics



Mechatronics Design Process

Mechatronic Design Conceptual

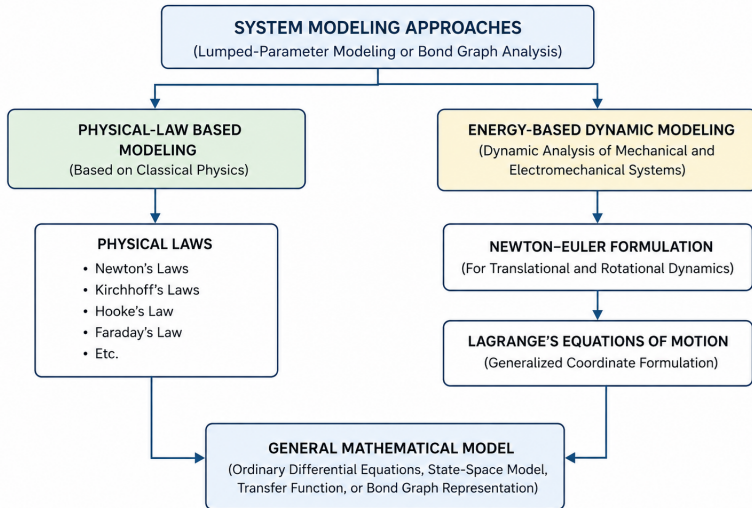


AI Classification



Case Study in Robotic System Modeling

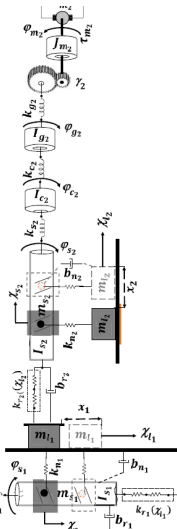
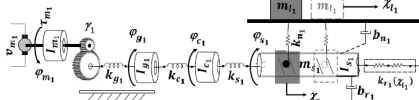
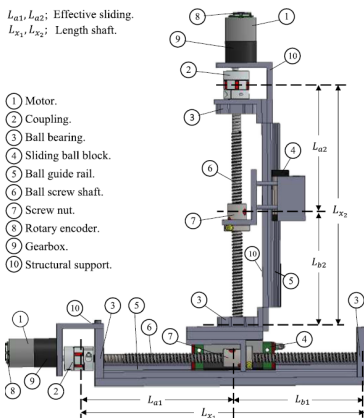
Methodology for system integration and obtaining the dynamic model



Ball screw mechanical system for feed drive

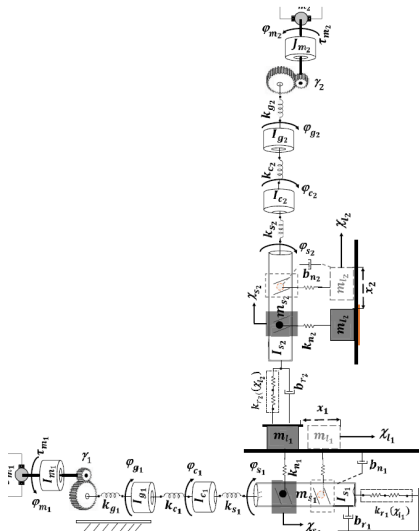
L_{a1}, L_{a2} : Effective sliding.
 L_{x1}, L_{x2} : Length shaft.

- 1) Motor.
- 2) Coupling.
- 3) Ball bearing.
- 4) Sliding ball block.
- 5) Ball guide rail.
- 6) Ball screw shaft.
- 7) Screw nut.
- 8) Rotary encoder.
- 9) Gearbox.
- 10) Structural support.



$$\begin{aligned}
 & I_{m1} \ddot{\varphi}_{m1} + b_{g1} \left[\dot{\varphi}_{m1} - \frac{\dot{\varphi}_{g1}}{\gamma_1} \right] + k_{g1} \nabla_1 = \tau_{m1}; \\
 & \left(\frac{I_{m1}}{\gamma_1^2} + \frac{I_{c1}}{3} \right) \ddot{\varphi}_{g1} - \frac{b_{g1}}{\gamma_1} \left[\dot{\varphi}_{m1} - \frac{\dot{\varphi}_{g1}}{\gamma_1} \right] - \frac{k_{g1}}{\gamma_1} \nabla_1 \\
 & \quad - k_{c1} \left[\varphi_{c1} - \varphi_{g1} \right] = 0; \\
 & \frac{I_{c1}}{3} \ddot{\varphi}_{c1} - k_{s1} \left[\varphi_{s1} - \varphi_{c1} \right] + k_{c1} \left[\varphi_{c1} - \varphi_{g1} \right] = 0; \\
 & \left(\frac{I_{c1}}{3} + I_{s1} \right) \ddot{\varphi}_{s1} - R_{n1} b_{n1} \left[\dot{\chi}_{l1} - \left(R_{n1} \dot{\varphi}_{s1} + \dot{\chi}_{s1} \right) \right] \\
 & \quad - R_{n1} k_{n1} \varepsilon_1 + k_{s1} \left[\varphi_{s1} - \varphi_{c1} \right] = 0; \\
 & \left(m_{s1} + m_{l1} \right) \ddot{\chi}_{s1} - b_{n1} \left[\dot{\chi}_{l1} - \left(R_{n1} \dot{\varphi}_{s1} + \dot{\chi}_{s1} \right) \right] \\
 & \quad + b_{r1} \dot{\chi}_{s1} - k_{n1} \varepsilon_1 + k_{r1} (\chi_{l1}) \chi_{s1} = 0; \\
 & m_{l1} \ddot{\chi}_{l1} + b_{n1} \left[\dot{\chi}_{l1} - \left(R_{n1} \dot{\varphi}_{s1} + \dot{\chi}_{s1} \right) \right] + k_{n1} \varepsilon_1 + f_{l1} \\
 & \quad + \frac{EA}{\left(L_1 - \chi_{l1} \right)^2} k_{r1} (\chi_{l1}) \chi_{s1} - k_{r2} (\chi_{l2}) \left(\chi_{s2} - \chi_{l1} \right) = 0; \\
 & I_{m2} \ddot{\varphi}_{m2} + b_{g2} \left[\dot{\varphi}_{m2} - \frac{\dot{\varphi}_{g2}}{\gamma_2} \right] + k_{g2} \nabla_2 = \tau_{m2}; \\
 & \left(\frac{I_{m2}}{\gamma_2^2} + \frac{I_{c2}}{3} \right) \ddot{\varphi}_{g2} - \frac{b_{g2}}{\gamma_2} \left[\dot{\varphi}_{m2} - \frac{\dot{\varphi}_{g2}}{\gamma_2} \right] - \frac{k_{g2}}{\gamma_2} \nabla_2 \\
 & \quad - k_{c2} \left[\varphi_{c2} - \varphi_{g2} \right] = 0; \\
 & \frac{I_{c2}}{3} \ddot{\varphi}_{c2} - k_{s2} \left[\varphi_{s2} - \varphi_{c2} \right] + k_{c2} \left[\varphi_{c2} - \varphi_{g2} \right] = 0; \\
 & \left(\frac{I_{c2}}{3} + I_{s2} \right) \ddot{\varphi}_{s2} - R_{n2} b_{n2} \left[\dot{\chi}_{l2} - \left(R_{n2} \dot{\varphi}_{s2} + \dot{\chi}_{s2} \right) \right] \\
 & \quad - R_{n2} k_{n2} \varepsilon_2 + k_{s2} \left[\varphi_{s2} - \varphi_{c2} \right] = 0; \\
 & \left(m_{s2} + m_{l2} \right) \ddot{\chi}_{s2} - b_{n2} \left[\dot{\chi}_{l2} - \left(R_{n2} \dot{\varphi}_{s2} + \dot{\chi}_{s2} \right) \right] \\
 & \quad + b_{r2} \dot{\chi}_{s2} - k_{n2} \varepsilon_2 + k_{r2} (\chi_{l2}) \left(\chi_{s2} - \chi_{l1} \right) = 0; \\
 & m_{l2} \ddot{\chi}_{l2} + b_{n2} \left[\dot{\chi}_{l2} - \left(R_{n2} \dot{\varphi}_{s2} + \dot{\chi}_{s2} \right) \right] + k_{n2} \varepsilon_2 + f_{l2} \\
 & \quad + \frac{EA}{\left(L_2 - \chi_{l2} \right)^2} k_{r2} (\chi_{l2}) \left(\chi_{s2} - \chi_{l1} \right) - m_{l2} g L_2 = 0;
 \end{aligned}$$

Ball screw mechanical system for feed drive

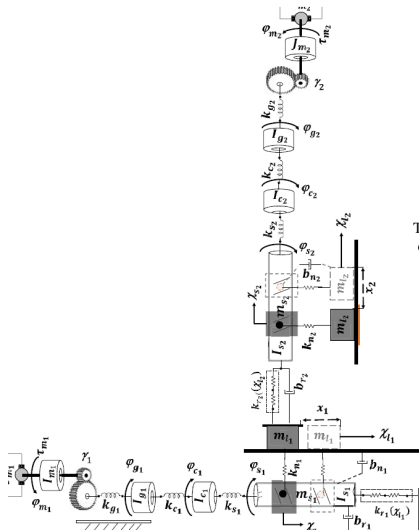


Due to the inertial and mass distribution, the kinetic energy K_T is expressed as

$$\begin{aligned}
K_T = & \frac{1}{2} \left[I_{m_1} \left(\dot{\varphi}_{m_1}^2 + \frac{\dot{\varphi}_{g_1}^2}{\gamma_1^2} \right) + I_{m_2} \left(\dot{\varphi}_{m_2}^2 + \frac{\dot{\varphi}_{g_2}^2}{\gamma_2^2} \right) \right] \\
& + \frac{1}{2} \left[I_{c_1} \left(\frac{\dot{\varphi}_{g_1}^2 + \dot{\varphi}_{c_1}^2 + \dot{\varphi}_{s_1}^2}{3} \right) + I_{s_1} \dot{\varphi}_{s_1}^2 \right] \\
& + \frac{1}{2} \left[I_{c_2} \left(\frac{\dot{\varphi}_{g_2}^2 + \dot{\varphi}_{c_2}^2 + \dot{\varphi}_{s_2}^2}{3} \right) + I_{s_2} \dot{\varphi}_{s_2}^2 \right] \\
& + \frac{1}{2} \left[\left(m_{s_1} + m_{l_1} \right) \dot{\chi}_{s_1}^2 + \left(m_{s_2} + m_{l_2} \right) \dot{\chi}_{s_2}^2 \right] \\
& + \frac{1}{2} \left[m_{l_1} \dot{\chi}_{l_1}^2 + m_{l_2} \dot{\chi}_{l_2}^2 \right] \quad (8)
\end{aligned}$$

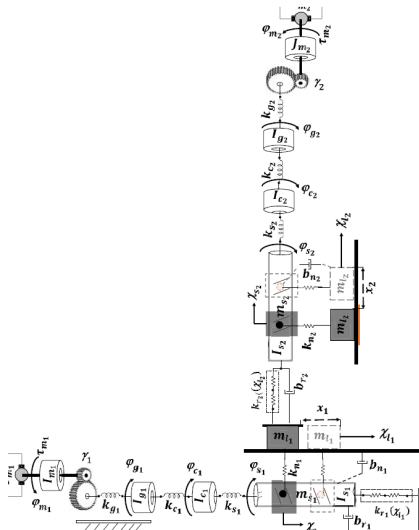
The equation is expressed as

$$\begin{aligned}
V_T = & \frac{1}{2} \left\{ k_{g1} \nabla_1^2 + k_{g2} \nabla_2^2 \right\} + \frac{1}{2} \left\{ k_{n1} \varepsilon_1^2 + k_{n2} \varepsilon_2^2 \right\} \\
& + \frac{1}{2} \left[k_{c1} \left(\varphi_{c1} - \varphi_{g1} \right)^2 + k_{c2} \left(\varphi_{c2} - \varphi_{g2} \right)^2 \right] \\
& + \frac{1}{2} \left[k_{s1} \left(\varphi_{s1} - \varphi_{c1} \right)^2 + k_{s2} \left(\varphi_{s2} - \varphi_{c2} \right)^2 \right] \\
& + \frac{1}{2} \left[k_{r1} (\chi_{l1}) \chi_{s1}^2 + k_{r2} (\chi_{l2}) \left(\chi_{s2} - \chi_{l1} \right)^2 \right] \\
& - m_{l2} g L_2 \chi_{l2}
\end{aligned} \quad (9)$$


$$\nabla_i = \begin{cases} \frac{1}{\gamma_i}(\gamma_i \varphi m_i - \varphi_{g_i} + \delta_i) & (\varphi m_i - \frac{\varphi_{g_i}}{\gamma_i}) \geq -\frac{\delta_i}{\gamma_i} \\ 0 & \frac{\delta_i}{\gamma_i} \leq (\varphi m_i - \frac{\varphi_{g_i}}{\gamma_i}) \\ 0 & -\frac{\delta_i}{\gamma_i} \geq (\varphi m_i - \frac{\varphi_{g_i}}{\gamma_i}) \\ \frac{1}{\gamma_i}(\gamma_i \varphi m_i - \varphi_{g_i} - \delta_i) & (\varphi m_i - \frac{\varphi_{g_i}}{\gamma_i}) \leq \frac{\delta_i}{\gamma_i} \end{cases} \quad (10)$$
$$\varepsilon_i = \begin{cases} \chi_{l_i} - x_i - \chi_{s_i} + \psi_i & (\chi_{l_i} - x_i - \chi_{s_i}) \leq -\psi_i \\ 0 & \psi_i \geq (\chi_{l_i} - x_i - \chi_{s_i}) \\ 0 & -\psi_i \leq (\chi_{l_i} - x_i - \chi_{s_i}) \\ \chi_{l_i} - x_i - \chi_{s_i} - \psi_i & (\chi_{l_i} - x_i - \chi_{s_i}) \geq \psi_i \end{cases} \quad (11)$$

where $i = 1, 2$, ε_i represent the axial deformation kinematics of the sliding table due to the contact force between the transmission mechanism of the ball screw and the nut; $x_i = R_{n_i} \varphi_{s_i}$ is the axial displacement by the rotation movement of the ball screw, ψ_i is a unknown axial backlash that is produced by the ball screw and the nut; $R_{n_i} = \frac{S_i}{2\pi\phi}$ which is the axial transmission resolution of the ball screw, ϕ is the efficiency of the ball screw. The rigidity parameters are based in the equa-

Ball screw mechanical system for feed drive



The Rayleigh dissipation function to overcome the friction forces in the micro-positioning system is used. Therefore, the frictional force can be expressed as follows

$$D_f = \frac{1}{2} \left[b_{g1} \left(\dot{\varphi}_{m1} - \frac{\dot{\varphi}_{g1}}{\gamma_1} \right)^2 + b_{r1} \dot{\chi}_{s1}^2 \right] + \frac{1}{2} b_{n1} \left[\dot{\chi}_{l1} - \left(R_{n1} \dot{\varphi}_{s1} + \dot{\chi}_{s1} \right) \right]^2$$

where b_{g1} , b_{r1} , and b_{n1} are the rotational damping driveshaft of the motor and gearbox, the axial damping of the screw, the axial damping of the nut and sliding table transmission, respectively, of axis 1 and 2.

The Lagrange method to obtain the dynamic model of a micro-positioning system is as follows [24]

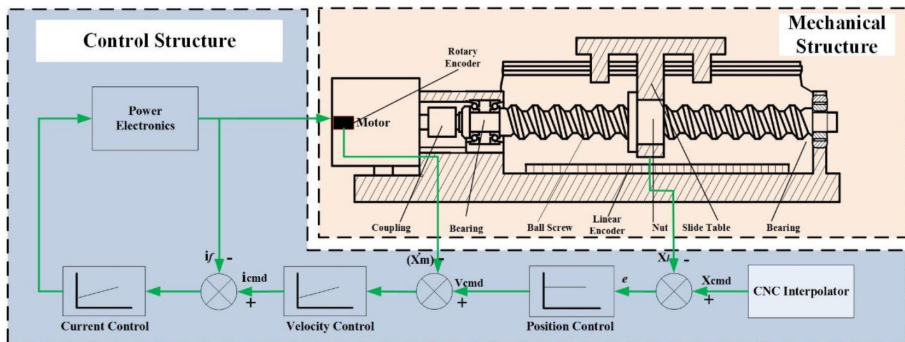
$$\frac{d}{dt} \left(\frac{\partial \mathcal{L}_T}{\partial (\dot{\varphi}, \dot{\chi})} \right) - \frac{\partial \mathcal{L}_T}{\partial (\varphi, \chi)} + \frac{\partial D_f}{\partial (\dot{\varphi}, \dot{\chi})} = \tau - f_i; \quad (16)$$

where

$$\mathcal{L}_T = K_T - V_T.$$

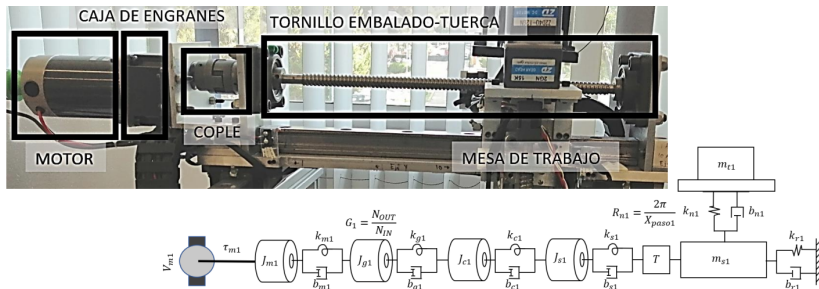
where $f_{li} = -\mu N \text{sgn}(S_r)$ is the coulomb friction force and it is independent of the contact area, μN is a tangential friction component μ is the sliding friction coefficient of the sliding block, and S_r is the relative sliding velocity.

General structure of a physical control system of feed-drive



Crédito a: Xing Liu, Xinyong Mao, et al., Method for identifying feed-drive system dynamic properties using a motor current, International Journal of Machine Tools and Manufacture, Volume 110, 2016.

Lumped parameter analysis and Lagrange Equation



$$K_1(\boldsymbol{\varphi}_1, \dot{\boldsymbol{\varphi}}_1) = \frac{1}{2}J_{m1}\dot{\theta}_{m1}^2 + \frac{1}{2}J_{g1}\dot{\theta}_{g1}^2 + \frac{1}{2}J_{c1}\dot{\theta}_{c1}^2 + \frac{1}{2}J_{s1}\dot{\theta}_{s1}^2 + \frac{1}{2}m_{s1}\dot{X}_{s1}^2 + \frac{1}{2}m_{t1}\dot{X}_{t1}^2$$

$$\mathcal{U}_1(\boldsymbol{\varphi}_1) = \frac{1}{2}k_{m1}(\theta_{m1} - G_1\theta_{g1})^2 + \frac{1}{2}k_{g1}(\theta_{g1} - \theta_{c1})^2 + \frac{1}{2}k_{c1}(\theta_{c1} - \theta_{s1})^2 + \frac{1}{2}k_{s1}(\theta_{s1} - R_{n1}X_{s1})^2 + \frac{1}{2}k_{r1}X_{s1}^2 + \frac{1}{2}k_{t1}(X_{s1} - X_{t1})^2$$

$$D_1(\boldsymbol{\varphi}_1, \dot{\boldsymbol{\varphi}}_1) = \frac{1}{2}b_{m1}(\dot{\theta}_{m1} - G_1\dot{\theta}_{g1})^2 + \frac{1}{2}b_{g1}(\dot{\theta}_{g1} - \dot{\theta}_{c1})^2 + \frac{1}{2}b_{c1}(\dot{\theta}_{c1} - \dot{\theta}_{s1})^2 + \frac{1}{2}b_{s1}(\dot{\theta}_{s1} - R_{n1}\dot{X}_{s1})^2 + \frac{1}{2}b_{r1}\dot{X}_{s1}^2 + \frac{1}{2}b_{t1}(\dot{X}_{s1} - \dot{X}_{t1})^2$$

$$\delta W_s(\boldsymbol{\varphi}_1) = \tau_{m1}\delta\theta_{m1}$$

Lumped parameter analysis and Lagrange Equation

Modelo dinámico

$$\frac{d}{dt} \left[\frac{\partial K(\mathbf{q}, \dot{\mathbf{q}})}{\partial \dot{\mathbf{q}}} \right] + \frac{\partial K(\mathbf{q}, \dot{\mathbf{q}})}{\partial \dot{\mathbf{q}}} - \frac{\partial \mathcal{U}(\mathbf{q}, \dot{\mathbf{q}})}{\partial \mathbf{q}} + \frac{\partial D(\mathbf{q}, \dot{\mathbf{q}})}{\partial \dot{\mathbf{q}}} = \frac{\partial \delta W(\mathbf{q}, \dot{\mathbf{q}})}{\partial \mathbf{q}} - F_s$$

$$J_{m1} \ddot{\theta}_{m1} + k_{m1}(\theta_{m1} - G_1 \theta_{g1}) + b_{m1}(\dot{\theta}_{m1} - G_1 \dot{\theta}_{g1}) = \tau_{m1}$$

$$J_{g1} \ddot{\theta}_{g1} + k_{m1} G_1 (G_1 \theta_{g1} - \theta_{m1}) + k_{g1}(\theta_{g1} - \theta_{c1}) + b_{m1} G_1 (G_1 \dot{\theta}_{g1} - \dot{\theta}_{m1}) + b_{g1}(\dot{\theta}_{g1} - \dot{\theta}_{c1}) = 0$$

$$J_{c1} \ddot{\theta}_{c1} + k_{g1}(\theta_{c1} - \theta_{g1}) + k_{c1}(\theta_{c1} - \theta_{s1}) + b_{g1}(\dot{\theta}_{c1} - \dot{\theta}_{g1}) + b_{c1}(\dot{\theta}_{c1} - \dot{\theta}_{s1}) = 0$$

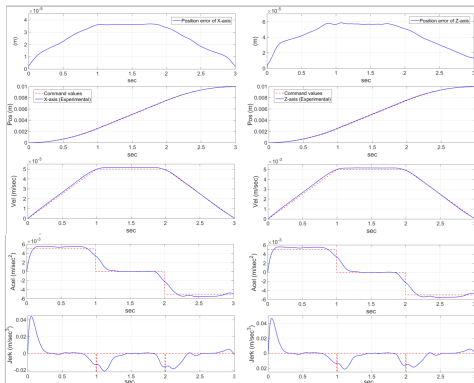
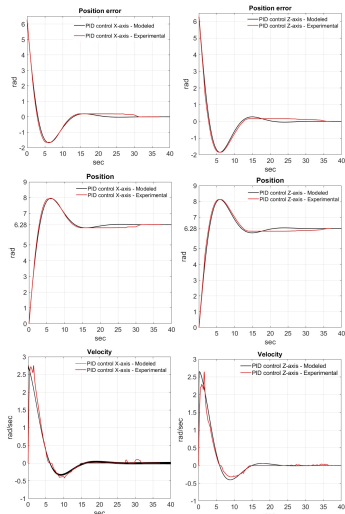
$$J_{s1} \ddot{\theta}_{s1} + k_{c1}(\theta_{s1} - \theta_{c1}) + k_{s1}(\theta_{s1} - R_{n1} X_{s1}) + b_{c1}(\dot{\theta}_{s1} - \dot{\theta}_{c1}) + b_{s1}(\dot{\theta}_{s1} - R_{n1} \dot{X}_{s1}) = 0$$

$$(m_{s1}) \ddot{X}_{s1} + k_{s1} R_{n1} (R_{n1} X_{s1} - \theta_{s1}) + k_{r1} X_{s1} + k_{t1} (X_{s1} - X_{t1}) + b_{s1} R_{n1} (R_{n1} \dot{X}_{s1} - \dot{\theta}_{s1}) + b_{r1} \dot{X}_{s1} + b_{t1} (\dot{X}_{s1} - \dot{X}_{t1}) = 0$$

$$(m_{t1}) \ddot{X}_{t1} + k_{t1} (X_{t1} - X_{s1}) + b_{t1} (\dot{X}_{t1} - \dot{X}_{s1}) + F_{s1} = 0$$



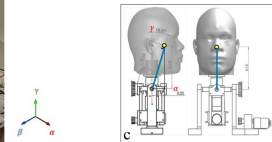
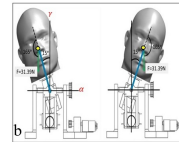
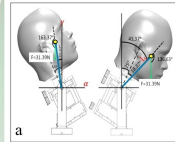
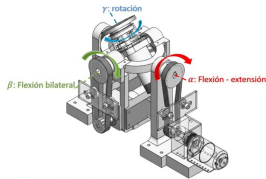
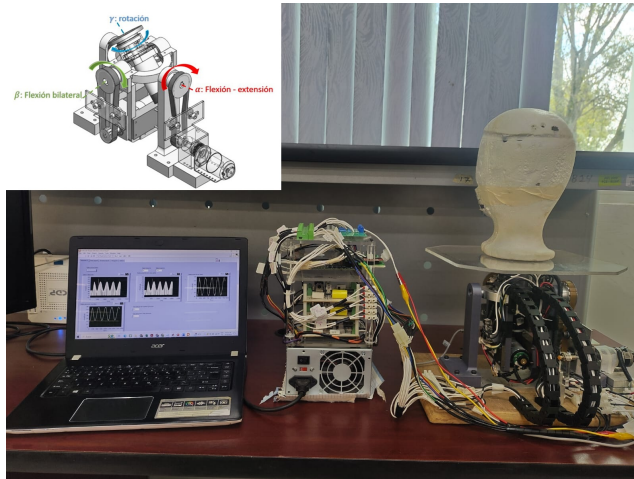
Hardware/software of the system



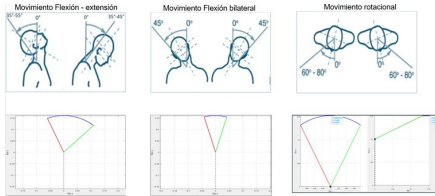
Description of the Cartesian feed-drive



Robotics Neck



Robotics Neck (Gabriela Aquino Gonzalez, PhD Student) Dynamic Model



$$E_c = \frac{1}{2} m \left((l_1 \cos(\theta_{h1}) \dot{\theta}_{h1})^2 + (l_1 \sin(\theta_{h1}) \dot{\theta}_{h1})^2 + (l_1 \cos(\theta_{h2}) \dot{\theta}_{h2})^2 + (l_1 \sin(\theta_{h2}) \dot{\theta}_{h2})^2 + (l_2)^2 \cos(\beta)^2 \dot{\theta}_{c3}^2 \right)$$

Para el primer grado de libertad se obtienen las siguientes ecuaciones correspondientes al modelo dinámico:

$$\begin{aligned} J_{m1} \ddot{\theta}_{m1} + K_{g1}(\theta_{m1} - G\theta_{g1}) + b_{m1} \dot{\theta}_{m1} - b_{g1}(G\dot{\theta}_{g1} - \dot{\theta}_{m1}) &= \tau_{m1} \\ J_{g1} \ddot{\theta}_{g1} - G K_{g1}(\theta_{m1} - G\theta_{g1}) + K_{c1}(\theta_{g1} - \theta_{c1}) + G b_{g1}(G\dot{\theta}_{g1} - \dot{\theta}_{m1}) \\ &\quad - b_{c1}(\dot{\theta}_{c1} - \dot{\theta}_{g1}) = 0 \\ J_{c1} \ddot{\theta}_{c1} - K_{c1}(\theta_{g1} - \theta_{c1}) + K_{p1}(\theta_{c1} - \theta_{p1}) + b_{c1}(\dot{\theta}_{c1} - \dot{\theta}_{g1}) - b_{p1}(\dot{\theta}_{p1} - \dot{\theta}_{c1}) \\ &= 0 \\ J_{p1} \ddot{\theta}_{p1} - K_{p1}(\theta_{c1} - \theta_{p1}) + G_B K_{h1}(G_B \theta_{p1} - \theta_{h1}) + b_{p1}(\dot{\theta}_{p1} - \dot{\theta}_{c1}) \\ &\quad - G_B b_{h1}(\dot{\theta}_{h1} - G_B \dot{\theta}_{p1}) = 0 \\ (J_{h1} + m(l_1)^2) \ddot{\theta}_{h1} - K_{h1}(G_B \theta_{p1} - \theta_{h1}) + b_{h1}(\dot{\theta}_{h1} - G_B \dot{\theta}_{p1}) + m g l_1 \sin(\theta_{h1}) \\ &= 0 \end{aligned}$$

Para el segundo grado de libertad las ecuaciones correspondientes al modelo dinámico son:

$$\begin{aligned} J_{m2} \ddot{\theta}_{m2} + K_{g2}(\theta_{m2} - G\theta_{g2}) + b_{m2} \dot{\theta}_{m2} - b_{g2}(G\dot{\theta}_{g2} - \dot{\theta}_{m2}) &= \tau_{m2} \\ J_{g2} \ddot{\theta}_{g2} - G K_{g2}(\theta_{m2} - G\theta_{g2}) + K_{c2}(\theta_{g2} - \theta_{c2}) + G b_{g2}(G\dot{\theta}_{g2} - \dot{\theta}_{m2}) \\ &\quad - b_{c2}(\dot{\theta}_{c2} - \dot{\theta}_{g2}) = 0 \\ J_{c2} \ddot{\theta}_{c2} - K_{c2}(\theta_{g2} - \theta_{c2}) + K_{p2}(\theta_{c2} - \theta_{p2}) + b_{c2}(\dot{\theta}_{c2} - \dot{\theta}_{g2}) - b_{p2}(\dot{\theta}_{p2} - \dot{\theta}_{c2}) \\ &= 0 \\ J_{p2} \ddot{\theta}_{p2} - K_{p2}(\theta_{c2} - \theta_{p2}) + G_B K_{h2}(G_B \theta_{p2} - \theta_{h2}) + b_{p2}(\dot{\theta}_{p2} - \dot{\theta}_{c2}) \\ &\quad - G_B b_{h2}(\dot{\theta}_{h2} - G_B \dot{\theta}_{p2}) = 0 \\ (J_{h2} + m(l_1)^2) \ddot{\theta}_{h2} - K_{h2}(G_B \theta_{p2} - \theta_{h2}) + b_{h2}(\dot{\theta}_{h2} - G_B \dot{\theta}_{p2}) + m g l_1 \sin(\theta_{h2}) \\ &= 0 \end{aligned}$$

Para el tercer grado de libertad las ecuaciones correspondientes al modelo dinámico son:

$$\begin{aligned} J_{m3} \ddot{\theta}_{m3} + K_{g3}(\theta_{m3} - G\theta_{g3}) + b_{m3} \dot{\theta}_{m3} - b_{g3}(G\dot{\theta}_{g3} - \dot{\theta}_{m3}) &= \tau_{m3} \\ J_{g3} \ddot{\theta}_{g3} - G K_{g3}(\theta_{m3} - G\theta_{g3}) + K_{c3}(\theta_{g3} - \theta_{c3}) + G b_{g3}(G\dot{\theta}_{g3} - \dot{\theta}_{m3}) \\ &\quad - b_{c3}(\dot{\theta}_{c3} - \dot{\theta}_{g3}) = 0 \\ (J_{c3} + m(l_1)^2 \cos(\beta)^2) \ddot{\theta}_{c3} - K_{c3}(\theta_{g3} - \theta_{c3}) + b_{c3}(\dot{\theta}_{c3} - \dot{\theta}_{g3}) &= 0 \end{aligned}$$

Constantes	Descripción
b_m	Coefficiente de fricción del motor [Nms/rad]
b_g	Coefficiente de fricción del primer reductor [Nms/rad]
b_c	Coefficiente de fricción del primer coque [Nms/rad]
b_p	Coefficiente de fricción del segundo reductor [Nms/rad]
b_h	Coefficiente de fricción del segundo coque [Nms/rad]
K_g	Rigidez del eje del primer reductor [Nm/rad]
k_c	Rigidez del eje del primer coque [Nm/rad]
K_p	Rigidez del eje del segundo reductor [Nm/rad]
K_h	Rigidez del eje del segundo coque [Nm/rad]
J_m	Inercia del motor [kgm ²]
J_g	Inercia del primer reductor [kgm ²]
J_c	Inercia del primer coque [kgm ²]
J_p	Inercia del segundo reductor [kgm ²]
J_h	Inercia del segundo coque [kgm ²]
m	Masa de la cabeza [kg]
l_1	Distancia del origen al centro de masa [m]

Robotics Neck (Gabriela Aquino Gonzalez, PhD Student) Results

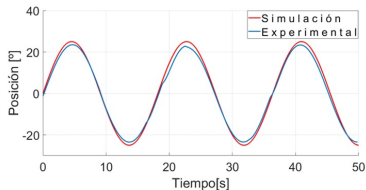


Figura 22. Posición en X: Comparación de datos simulados y datos experimentales.

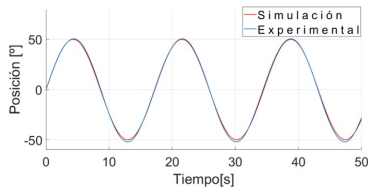


Figura 24. Posición en Z: Comparación de datos simulados y datos experimentales.

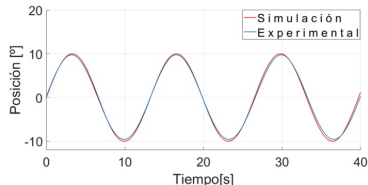
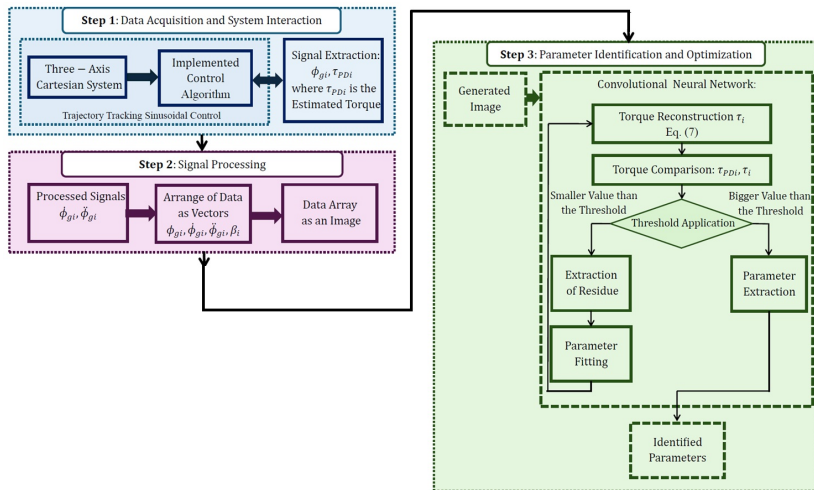


Figura 23. Posición en Y: Comparación de datos simulados y datos experimentales.

Flowchart of the proposed identification procedure



Case Study of Remaining Service Life of Oil Pipeline

Introduction



Propósito de la inspección

Su finalidad es prevenir contratiempos y garantizar la integridad del sistema durante su funcionamiento.



Causa principal y frecuencia

Las inspecciones periódicas se realizan principalmente para detectar y monitorear la corrosión.



Importancia de medir la corrosión

Conocer la velocidad de corrosión interna ayuda a estimar la vida útil restante de la tubería en servicio.

Introduction

Entidades que establecen y supervisan las normas • • del sector petrolero • •



Las regulaciones del sector petrolero son emitidas, administradas y supervisadas por instituciones, secretarías y organismos especializados que promueven el orden, la eficiencia y la seguridad bajo estándares rigurosos y objetivos definidos.

Entidades nacionales



Organismos internacionales



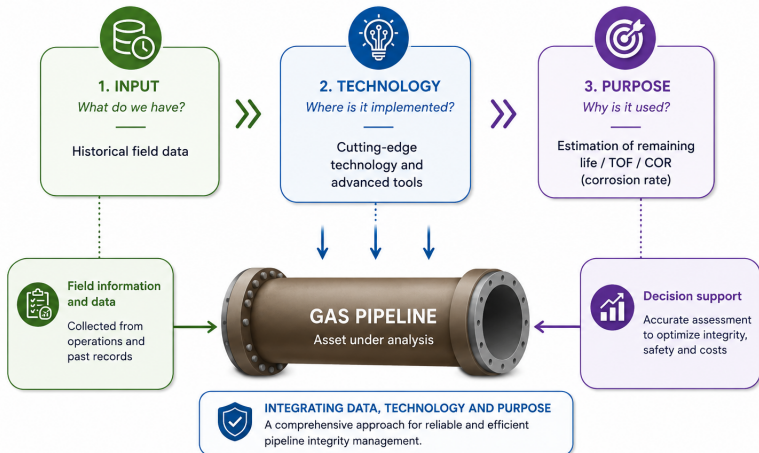
Organismos de estandarización y seguridad



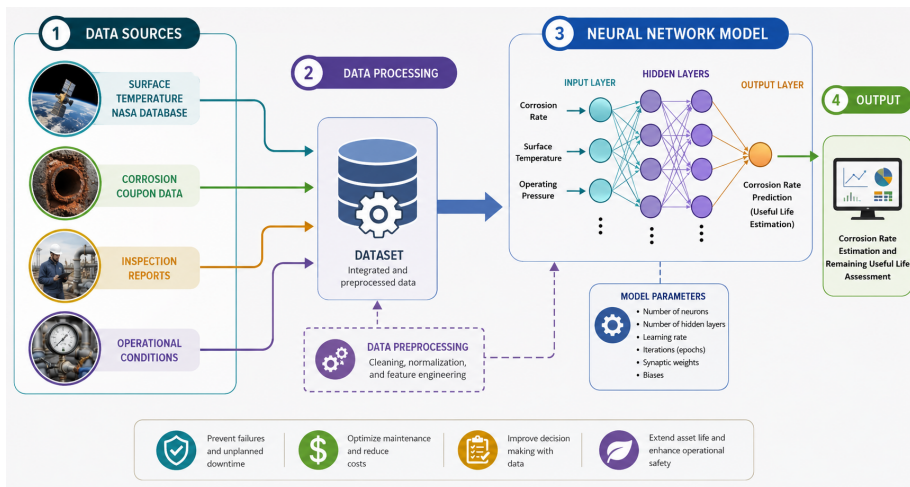
Problema principal

Assessing the service life of pipelines in the field, taking into account internal corrosion, involves high operating costs and significant methodological complexity. Furthermore, the limited availability of data makes it difficult to implement models that are applicable under real operating conditions. Therefore, this research focused on developing an advanced tool that, by analyzing historical data from a gas pipeline, would enable the prediction of TVR with an accuracy similar to that obtained through electronic Intelligent In-Line Inspection (ILI) systems, thereby contributing to more efficient pipeline integrity management.

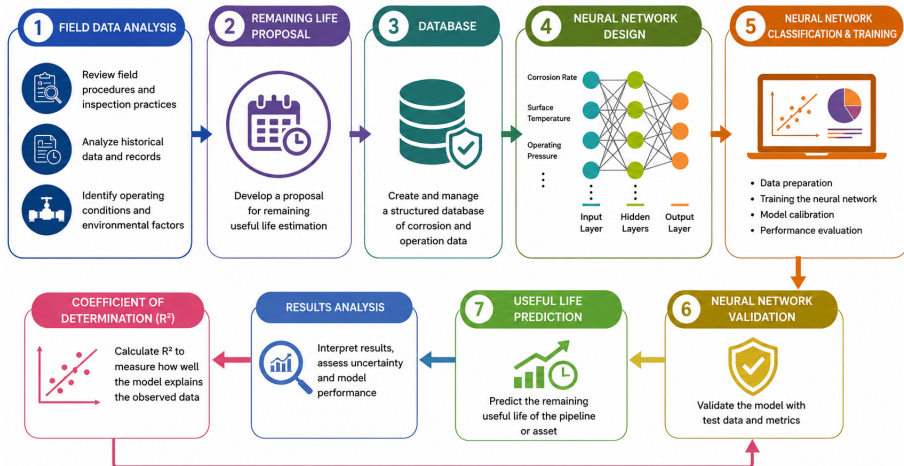
Proposed



Proposed

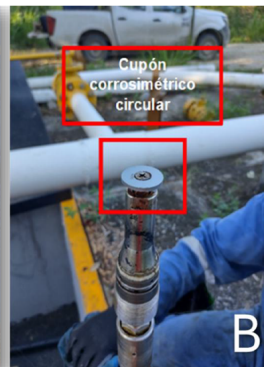
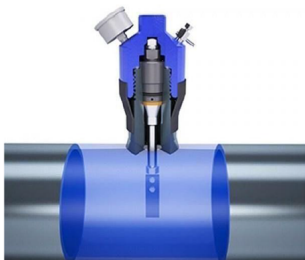


Methodology



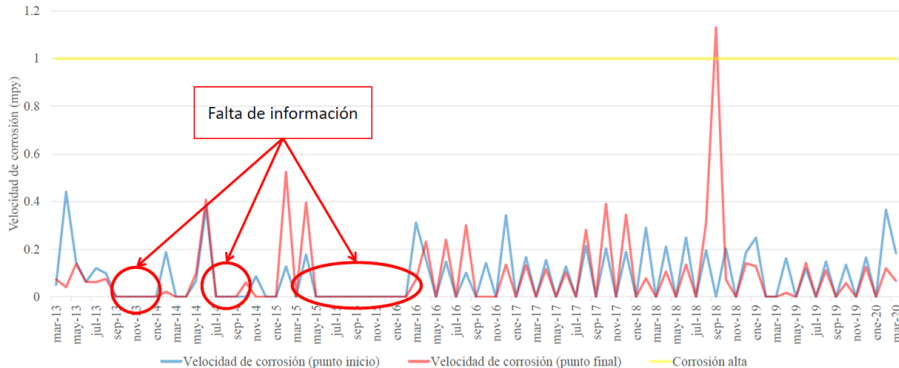
Field Operations

Field Operations



Historical Evaluation Report, REALIZED BY RODRIGO ALAMILLA VAZQUEZ, MsC.

Velocidad de corrosión interna en Gasoducto



Results, REALIZED BY RODRIGO ALAMILLA VAZQUEZ, MSc.

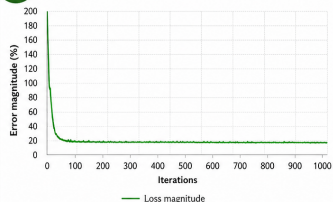


TEST 2 – MODEL CONFIGURATION

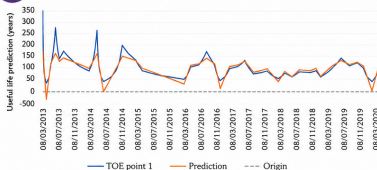
GRAPH	A	B	C
Number of neurons	5	3	3
Number of hidden layers	1	5	10
Learning rate	0.1		
Number of iterations	1000 iterations		



LOSS FUNCTION



REAL FUNCTION VS PREDICTED FUNCTION BY THE ANN



MODEL PERFORMANCE RESULTS

Test	Training Accuracy	Validation Accuracy	Test Accuracy
2	81.91%	82.44%	82.51%

Future Works

CONCLUSIONES Y LÍNEAS DE TRABAJO FUTURAS

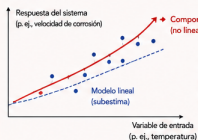
Finalmente, se concluye que una de las principales limitaciones del estudio es la posible inadecuación del enfoque lineal para representar la dinámica real del sistema. Por ello, se plantea como línea de trabajo futura la implementación de **modelos no lineales más avanzados**, incluyendo modelos matemáticos ajustados específicamente al fenómeno, que integren variables críticas como la corrosión, la temperatura y la presión, así como los parámetros químicos del fluido que circula en la tubería. Aunque este tipo de modelado implica un análisis más profundo y un mayor tiempo de desarrollo, se espera que permita mejorar significativamente la precisión de las predicciones y fortalecer la evaluación de la integridad mecánica de los sistemas de transporte de gas.

1. LIMITACIÓN IDENTIFICADA

Posible inadecuación del enfoque lineal

Los modelos lineales pueden no capturar comportamientos complejos y variaciones no proporcionales en la dinámica real del sistema.

Ejemplo:



En la práctica, la velocidad de corrosión puede aumentar de forma acelerada a partir de cierto umbral de temperatura, lo cual un modelo lineal no logra representar adecuadamente.

2. LÍNEA DE TRABAJO FUTURA

Implementación de modelos no lineales más avanzados

Desarrollar e implementar modelos matemáticos que representen mejor la dinámica real del sistema, incorporando variables críticas y propiedades del fluido.

Variables críticas a integrar (con ejemplos):



Corrosión

Ej.: Tasa de corrosión (interna/externa) medida en mm/año.



Temperatura

Ej.: Variaciones térmicas a lo largo del tiempo y del recorrido.



Presión

Ej.: Cambios de presión operativa por demanda o condiciones.



Parámetros químicos del fluido

Ej.: pH, contenido de CO_2 , H_2S , sales (disueltos).

Ejemplo de aplicación:



Datos históricos y monitoreo en campo



Modelo no lineal (p.ej., redes neuronales, SVM, modelos híbridos)



Predicciones más precisas y realistas para la toma de decisiones

Conclusions

- Today's mechatronics is an emerging discipline for industries that require more versatile, low-cost and intelligent technologies.
- Nowadays, it is not only necessary to start up a system, it is necessary to address the problems that present themselves in the mechatronics systems and solve them with modern techniques that help to **optimization, accuracy, service life estimation, diagnostics and failure prediction**.
- The future of intelligent mechatronics is physical modeling and virtualization (digital twin) with the use of artificial intelligence. That is, we are close to the evolution towards industry 5.0.



División Académica de
Ingeniería y Arquitectura

THANK YOU!