



**UNIVERSIDAD DE LAS FUERZAS ARMADAS ESPE**

**DEPARTAMENTO DE ELÉCTRICA Y ELECTRÓNICA**

**CARRERA DE INGENIERÍA EN ELECTRÓNICA E INSTRUMENTACIÓN**

**Artículo Académico Previo a la Obtención del Título de Ingeniero en  
Electrónica e Instrumentación**

**CONSTRUCCIÓN Y CONTROL DE ROBOT MANIPULADOR AÉREO**

**Autores:**

Bejarano Rodríguez, Alan Ricardo

Loor Vera, Steeven José

Ing. Silva, Franklin M. Mg. *Tutor*

Ing. Andaluz, Víctor H. Ph D. *Cotutor*



# IEA/AIE 2020

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21-24, July, 2020 --> 22-25, September, 2020 (postponed!)  
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Authors [Authors and affiliations](#)

Steeven J. Loor , Alan R. Bejarano , Franklin M. Silva , Víctor H. Andaluz 

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### Construction and Control Aerial Manipulator Robot

Steeven J. Loor<sup>(✉)</sup>, Alan R. Bejarano<sup>(✉)</sup>, Franklin M. Silva<sup>(✉)</sup>,  
and Víctor H. Andaluz<sup>(✉)</sup>

Universidad de Las Fuerzas Armadas ESPE, Sangolquí, Ecuador  
(sjloor, arbejarano2, fmsilva, vhandaluz1)@espe.edu.ec

**Abstract.** This article presents the construction of an aerial manipulator robot composed of one or two robotic arms on an unmanned aerial vehicle, in order to execute control tasks in an autonomous or tele-operated manner. This aerial manipulator robot can work with one or two arms depending on the application requirements. The arms have been designed to serve several purposes: object manipulation and protect the actuating servos against direct impacts and overloads. Finally, a trajectory tracking algorithm is implemented and the simulation results are presented and discussed, which validate the controller and the proposed modeling.

**Keywords:** UAV · Robotic arms · Aerial manipulator robot

### 1 Introduction

During the last decades, research in robotics has been oriented to find solutions to the technical needs of applied robotics. Today, the creation of new needs and markets outside the traditional manufacturing robotics market (e.g., cleaning, mine clearance, construction, shipbuilding, agriculture) and the world in which we live is demanding field and service robots to serve the new market and human social needs [1]. The International Federation of Robotics defines a service robot as a semi- or fully autonomous operated robot that performs useful services for humans and is not used for manufacturing [2]. They are those robotic systems that help people in their daily lives at work, at home, in leisure, and as part of the assistance to the disabled and the elderly. In other words, any robot used in the medical, health, military, domestic and educational industries is considered a service robot [3]. The UAVs have been widely used in military applications, Applications in agriculture and industrial environments are currently being exploited [5, 6, 7, 8]. There are several control strategies for UAVs some of which are energy optimization [9, 10] and fuzzy control.

The UAV industry is growing very rapidly due to the use of UAVs in commercial areas. However, unmanned aerial vehicles often do not meet the needs of complicated missions such as object handling, as they are only able to navigate in spaces that are difficult to access. For this reason, it is proposed to incorporate one or two robotic arms on an aerial platform (UAV). The combination of aerial mobile platforms with

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## IX. CONCLUSIONS

This document presents a novel airborne mobile manipulator consisting of a combination of mechanical and control development strategies.

It has the capacity to have modular arms (one or two arms depending on the application that requires it) and a kinematic controller responsible for carrying out the trajectory tracking task.

The law of control proposed here lies in its simplicity and ease of application, compared to others already available in the literature.

104 STEVEN JOSE LO...  
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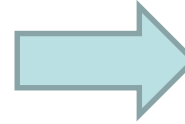
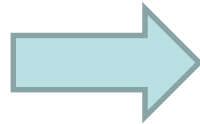
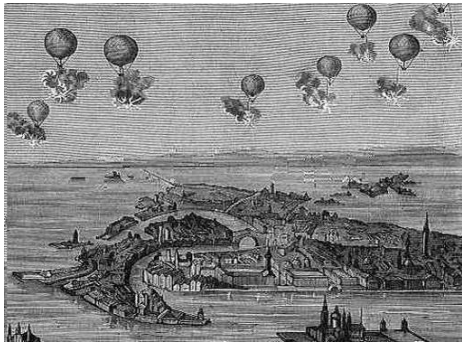
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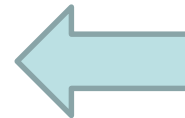
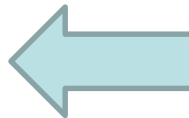








# Introducción



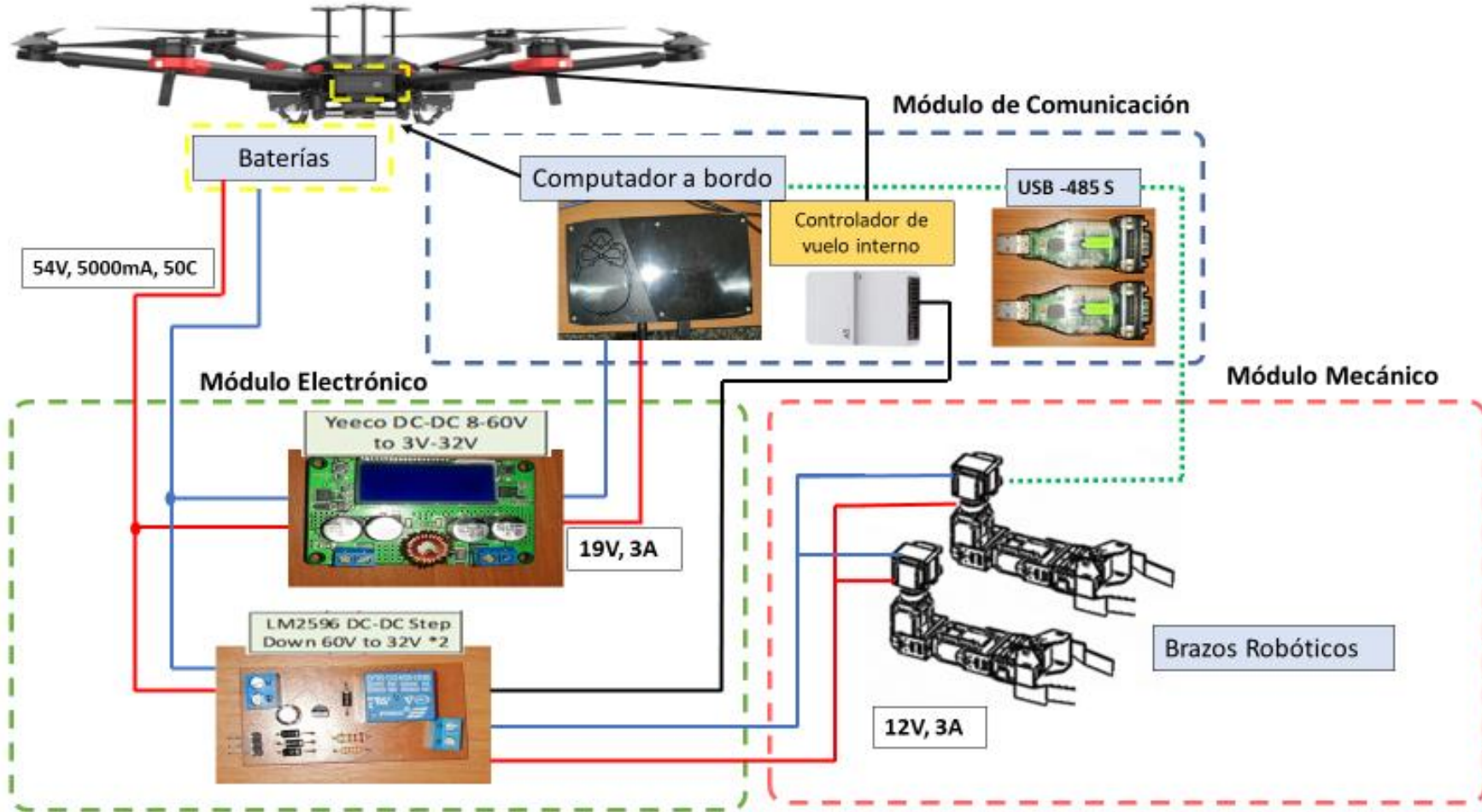
Implementar uno o dos **brazos robóticos** en un vehículo aéreo no tripulado, a fin de ejecutar tareas de control autónomo.

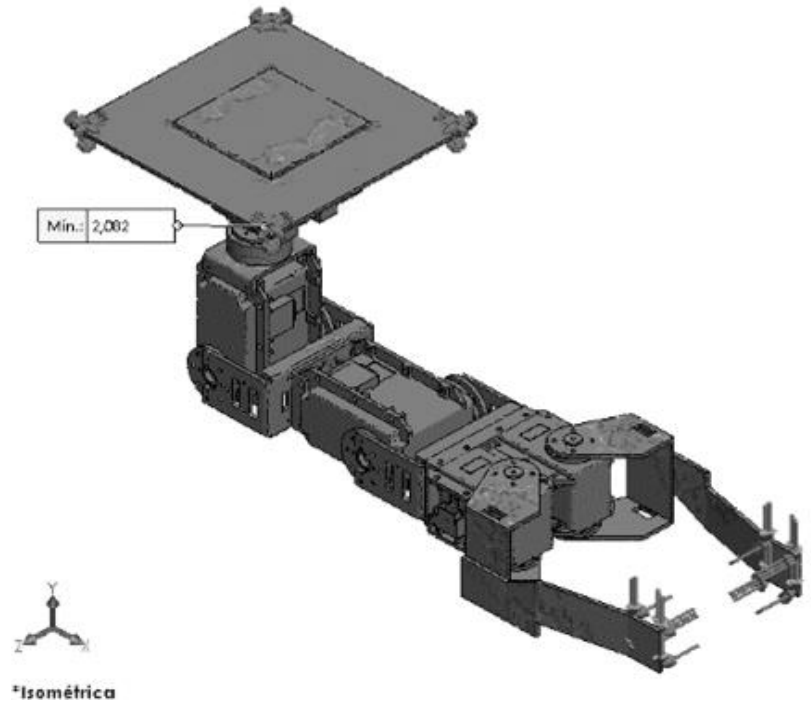
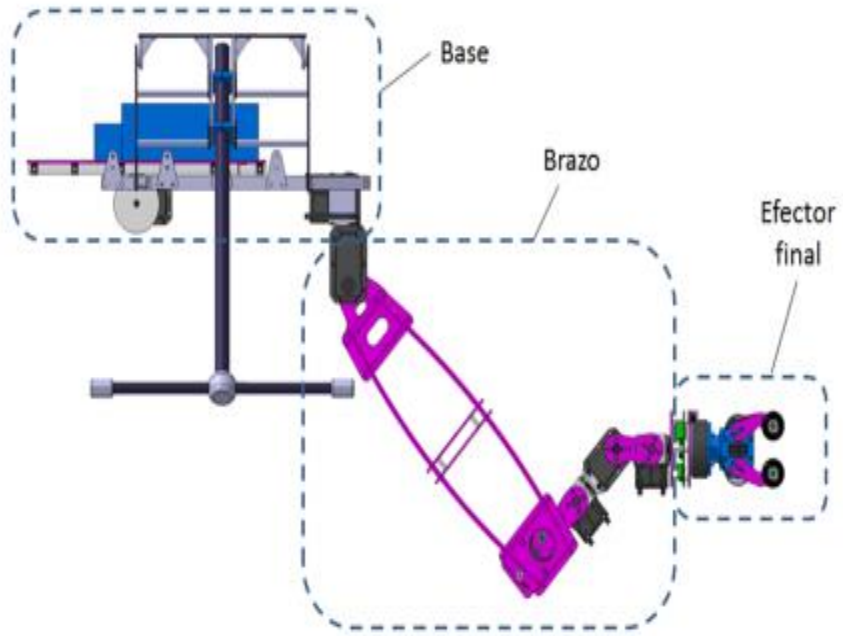
- ✓ Investigar acerca de la **estructura mecánica-electrónica** de los vehículos aéreos no tripulados (con siglas en inglés UAV), a fin de implementar uno o dos brazos robóticos sobre el UAV, además investigar sobre estructuras y funcionamiento de brazos robóticos.
- ✓ Implementar la electrónica y mecánica necesaria sobre un UAV a fin de **construir un nuevo sistema robótico acoplado**, conformado por el UAV y uno o dos brazos robóticos.
- ✓ Implementar la **comunicación bilateral entre el UAV** y los dos brazos robóticos a fin de que implemente algoritmos de control en lazo cerrado.
- ✓ Desarrollar un **control de posición en lazo cerrado** para el control autónomo de un robot manipulador aéreo (UAV más uno o dos brazos robóticos).
- ✓ Desarrollar **pruebas experimentales del algoritmo de control** propuesto sobre el sistema robótico acoplado, con el propósito de evaluar el desempeño de la construcción mecánica-eléctrica del robot desarrollado.

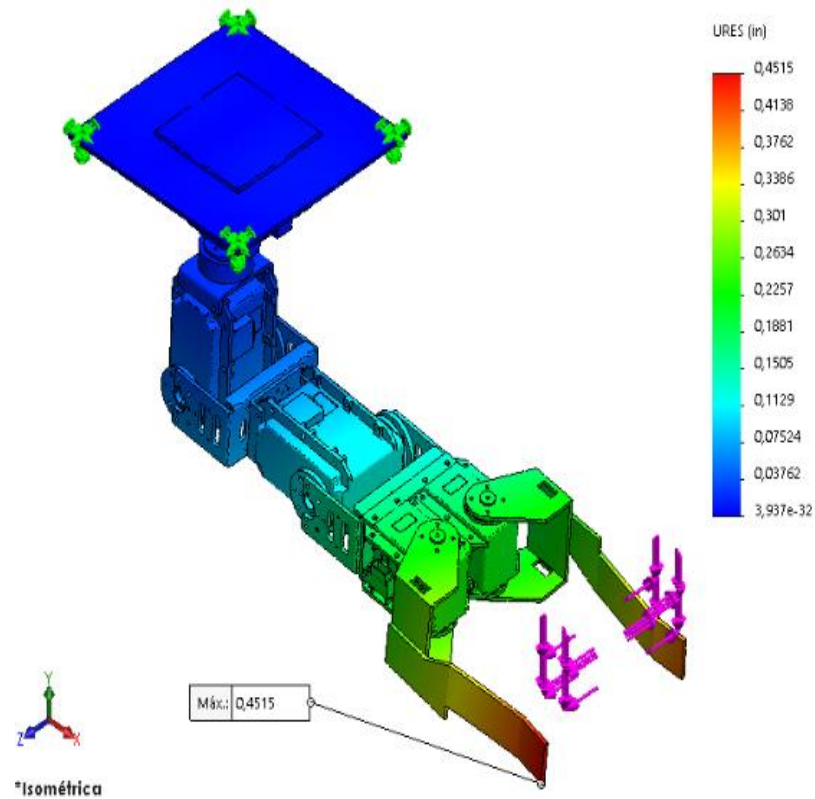
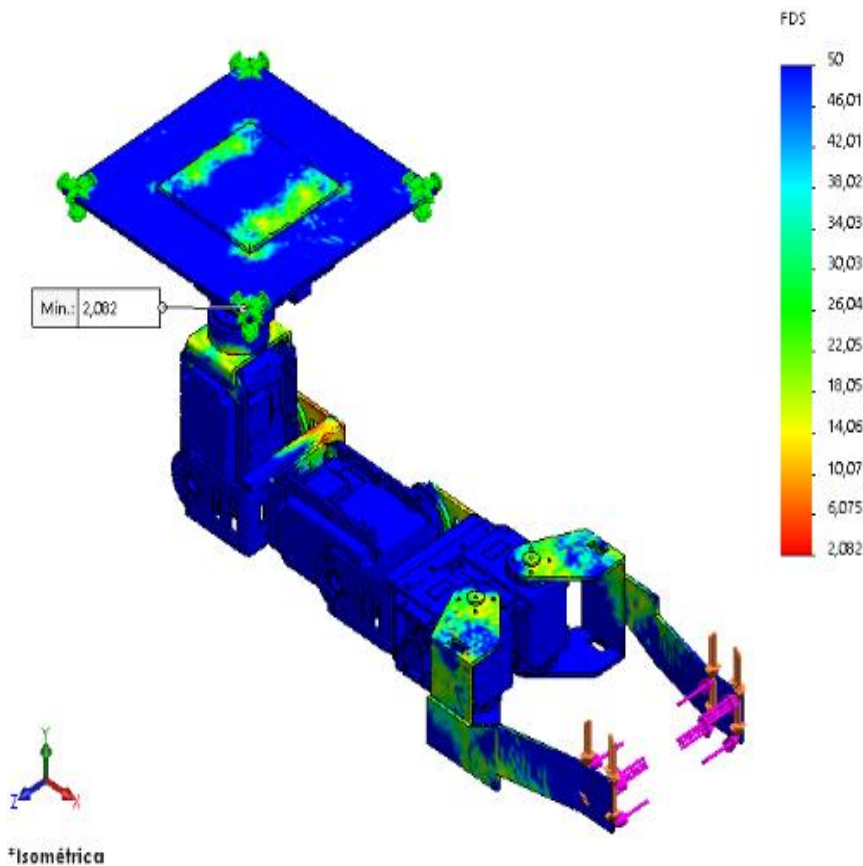




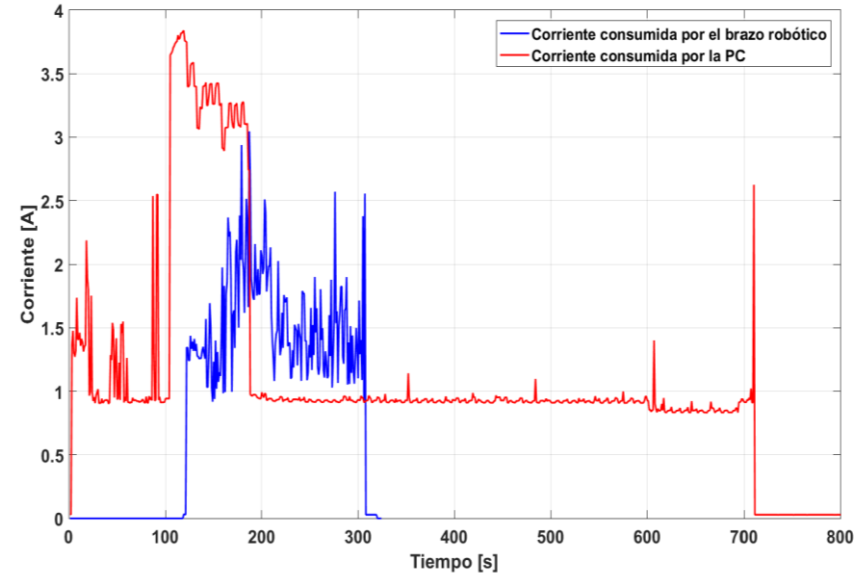
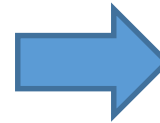
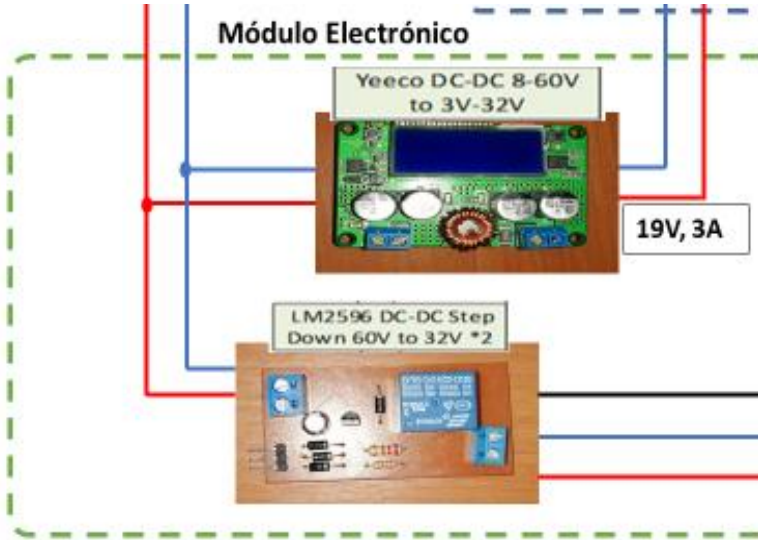
# Manipulador Aéreo



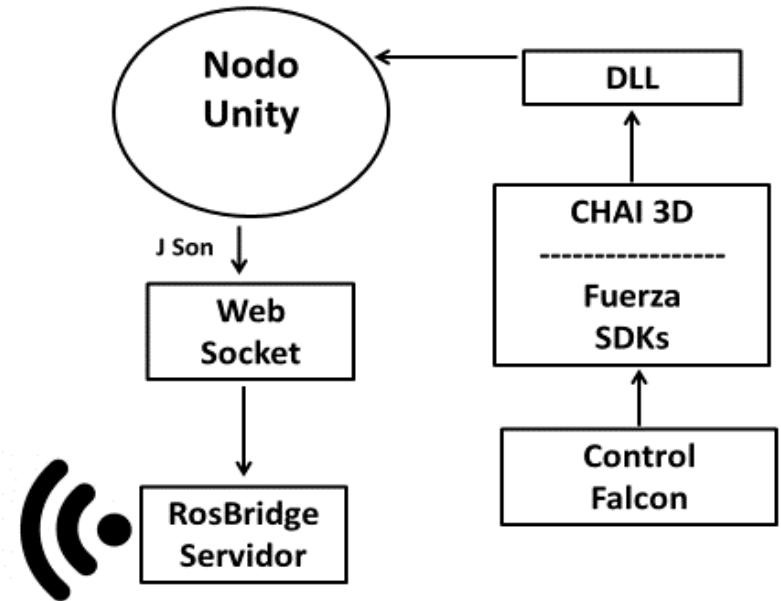
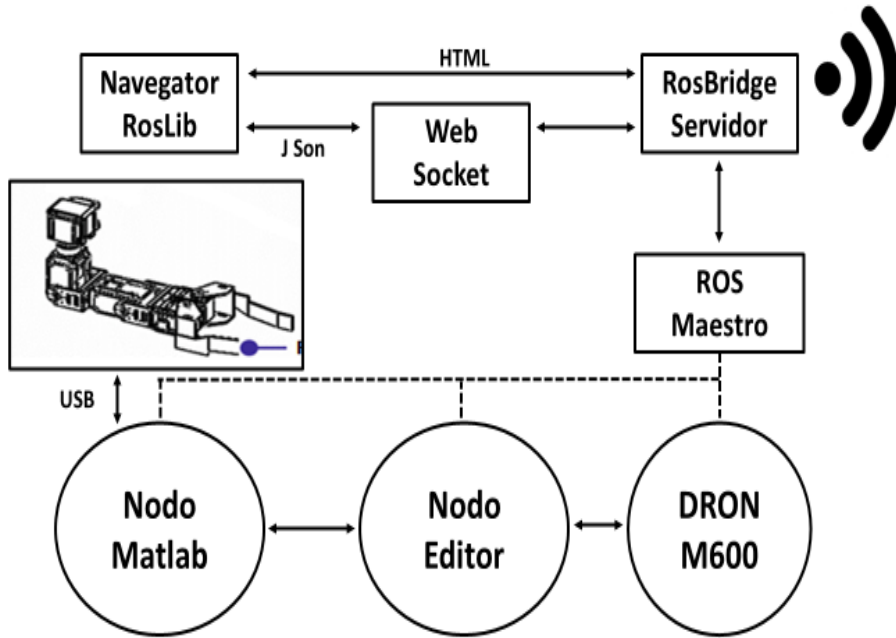




## Circuitos de Potencia y Protección

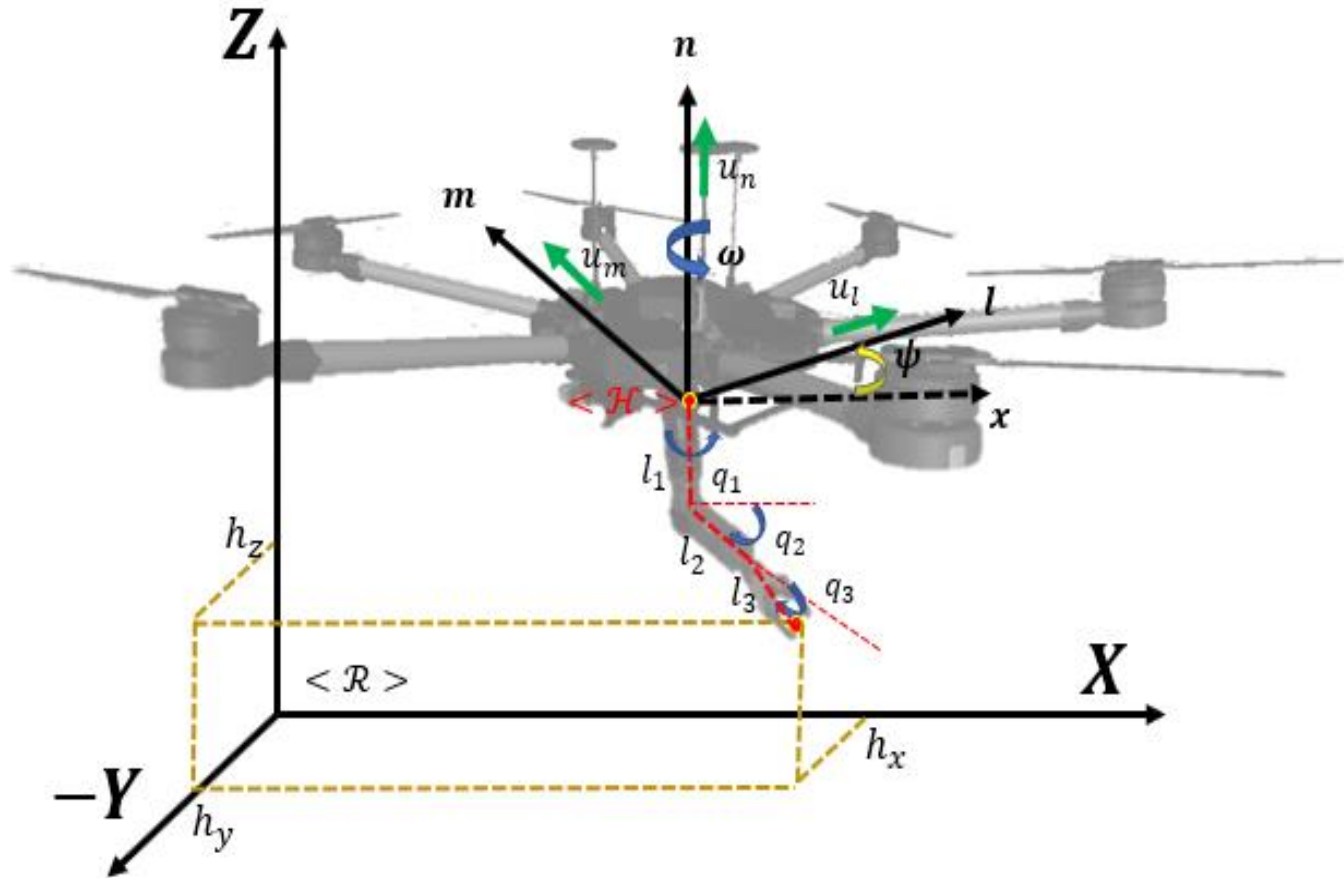








## Modelación con un Brazo Robótico



## Modelo Cinemático de forma Compacta

$$\dot{\mathbf{h}}(t) = \mathbf{J}(q, \psi) \mathbf{v}(t)$$

$$\left. \begin{aligned} \dot{h}_x &= u_l C_\Psi - u_m S_\Psi + I_2 S_{q_2} C_{\Psi q_1} \dot{q}_2 + I_2 C_{q_2} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ &+ I_3 S_{q_2 q_3} C_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) + I_3 C_{q_2 q_3} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{h}_y &= u_l S_\Psi - u_m C_\Psi + I_2 S_{q_2} C_{\Psi q_2} \dot{q}_2 - I_2 C_{q_2} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ &+ I_3 S_{q_2 q_3} S_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) - I_3 C_{q_2 q_3} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{h}_z &= u_n - l_1 - l_2 S_{q_2} - I_3 S_{q_2 q_3} \end{aligned} \right\}$$

Donde:

$$\mathbf{v} = \left[ u_l \quad u_m \quad u_n \quad \omega \quad \dot{q}_1 \quad \dot{q}_2 \quad \dot{q}_3 \right]^T \quad \text{Acciones de control}$$

$$\mathbf{J}(q, \psi) \in \mathbb{R}^{m \times n} \quad \text{Matriz Jacobiana}$$





Punto de interés  $\mathbf{h}_1$

$$\left\{ \begin{array}{l} \dot{\mathbf{h}}_x = u_l C_\Psi - u_m S_\Psi - \omega a S_\Psi + I_2 S_{q_2} C_{\Psi q_1} \dot{q}_2 + I_2 C_{q_2} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \quad + I_3 S_{q_2 q_3} C_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) + I_3 C_{q_2 q_3} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{\mathbf{h}}_y = u_l S_\Psi - u_m C_\Psi + \omega a C_\Psi + I_2 S_{q_2} C_{\Psi q_2} \dot{q}_2 - I_2 C_{q_2} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \quad + I_3 S_{q_2 q_3} S_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) - I_3 C_{q_2 q_3} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{\mathbf{h}}_z = u_n - l_1 - l_2 S_{q_2} - I_3 S_{q_2 q_3} \end{array} \right\}$$

Punto de interés  $\mathbf{h}_2$

$$\left\{ \begin{array}{l} \dot{\mathbf{h}}_x = u_l C_\Psi - u_m S_\Psi + \omega a S_\Psi + I_2 S_{q_2} C_{\Psi q_1} \dot{q}_2 + I_2 C_{q_2} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \quad + I_3 S_{q_2 q_3} C_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) + I_3 C_{q_2 q_3} S_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{\mathbf{h}}_y = u_l S_\Psi - u_m C_\Psi - \omega a C_\Psi + I_2 S_{q_2} C_{\Psi q_2} \dot{q}_2 - I_2 C_{q_2} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \quad + I_3 S_{q_2 q_3} S_{\Psi q_1} (\dot{q}_2 + \dot{q}_3) - I_3 C_{q_2 q_3} C_{\Psi q_1} (\dot{\Psi} + \dot{q}_1) \\ \dot{\mathbf{h}}_z = u_n - l_1 - l_2 S_{q_2} - I_3 S_{q_2 q_3} \end{array} \right\}$$

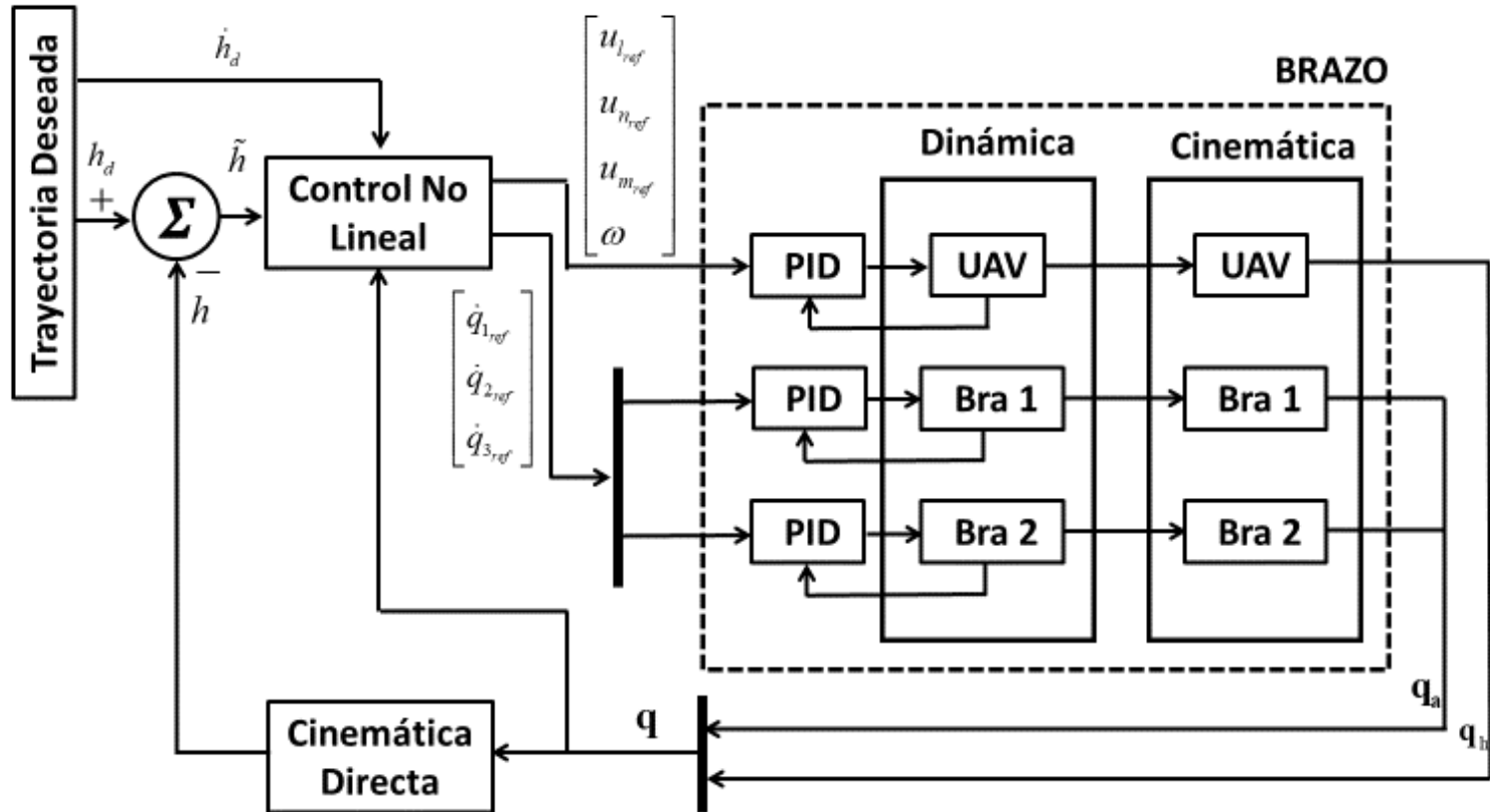
Modelo Cinemático de Forma Compacta

$$\dot{\mathbf{h}} = \begin{bmatrix} \dot{\mathbf{h}}_1 \\ \dot{\mathbf{h}}_2 \end{bmatrix} = [\mathbf{J}] \mathbf{v}_q(t)$$



# Esquema de Control Unificado

Se presenta un esquema de control autónomo en lazo cerrado que valida la construcción y el canal de comunicación.



Se diseñará en base al Modelo Cinemático del robot manipulador el cual es el siguiente:

$$\dot{\mathbf{h}}(t) = \mathbf{J}(q, \psi) \mathbf{v}(t)$$

$$\dot{\mathbf{h}}\mathbf{J}^{-1} = \mathbf{J}^{-1}\mathbf{J}\dot{\mathbf{q}}$$

$$\mathbf{V}_{\text{ref}} = \mathbf{J}^{-1} (\dot{\mathbf{h}}_d + \mathbf{k}\tilde{\mathbf{h}})$$

Control de Trayectoria  $\mathbf{V}_{\text{ref}}(t) = \mathbf{J}^{\#} (\dot{\mathbf{h}}_d + \mathbf{K}_1 \tanh(\mathbf{K}_2 \tilde{\mathbf{h}}))$

Control de Posición  $\mathbf{V}_{\text{ref}}(t) = \mathbf{J}^{\#} (\mathbf{K}_1 \tanh(\mathbf{K}_2 \tilde{\mathbf{h}})) \quad \dot{\mathbf{h}}_d = 0$

Considerando un seguimiento perfecto de la velocidad :

$$\mathbf{V} \equiv \mathbf{V}_c \quad \text{entonces: } \tilde{\mathbf{h}}(t) \rightarrow \mathbf{0} \text{ y } t \rightarrow \infty$$

Se debe encontrar la ecuación en lazo cerrado y se deja en función de los errores :

$$\left( \mathbf{v}_{hd} - \dot{\tilde{\mathbf{h}}} \right) + \mathbf{K}_c \tanh(\mathbf{K}\tilde{\mathbf{h}}) = \mathbf{0} \quad (1)$$

$$\mathbf{V}(\tilde{\mathbf{h}}) = \frac{1}{2} \tilde{\mathbf{h}}^T \tilde{\mathbf{h}} \quad (2)$$

$$\dot{\mathbf{V}}(\tilde{\mathbf{h}}) = \tilde{\mathbf{h}}^T \Upsilon - \tilde{\mathbf{h}}^T \mathbf{K}_c \tanh(\mathbf{K}\tilde{\mathbf{h}}) \quad (3)$$

$$\left\| \tilde{\mathbf{h}}^T \mathbf{k}_c \tanh(\mathbf{k}\tilde{\mathbf{h}}) \right\| > \left\| \tilde{\mathbf{h}}^T \boldsymbol{\gamma} \right\|$$



Para valores grandes  $\tilde{\mathbf{h}}$  :

$$\|\mathbf{K}_c\| > \frac{\|\Upsilon\|}{\tanh(k_{\text{aux}})}$$

Para valores pequeños  $\tilde{\mathbf{h}}$ :

$$\|\tilde{\mathbf{h}}\| > k_{\text{aux}} \frac{\|\Upsilon\|}{\lambda_{\min}(\mathbf{K}) \tanh(k_{\text{aux}})}$$

Por lo tanto  $\tilde{\mathbf{h}}$  esta limitado por:

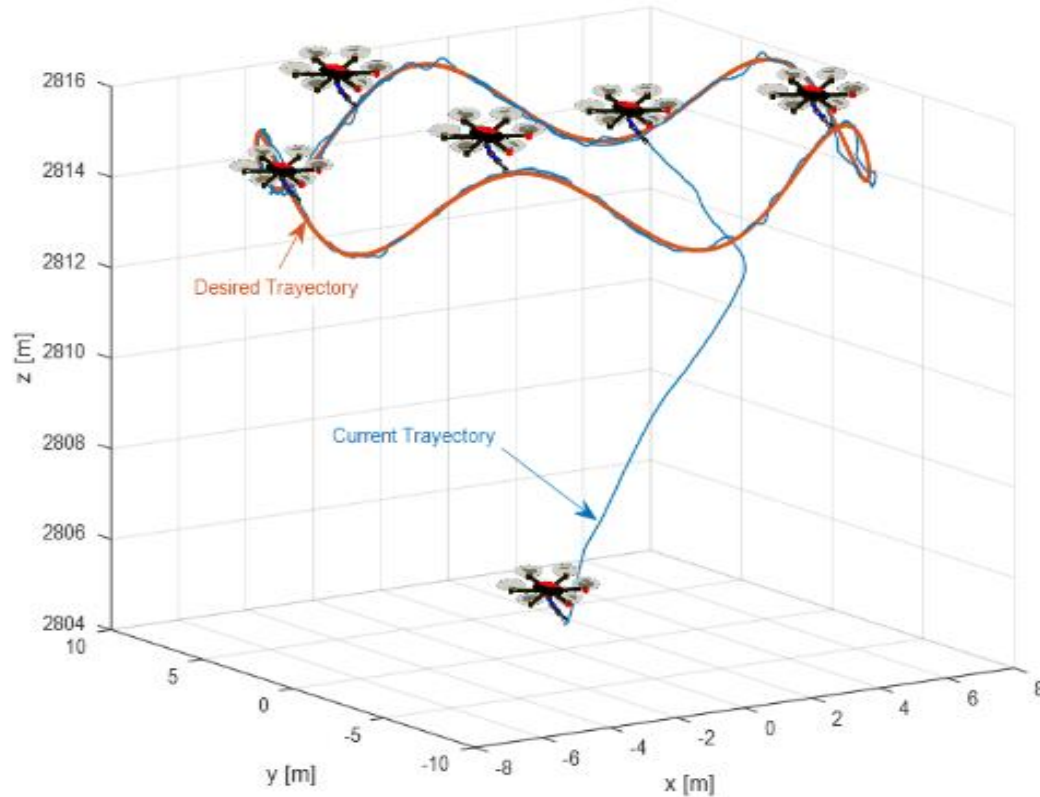
$$\|\tilde{\mathbf{h}}\| \leq \frac{k_{\text{aux}} \|\Upsilon\|}{\zeta \lambda_{\min}(\mathbf{K}) \tanh(k_{\text{aux}})} \quad \text{con } 0 < \zeta < 1$$



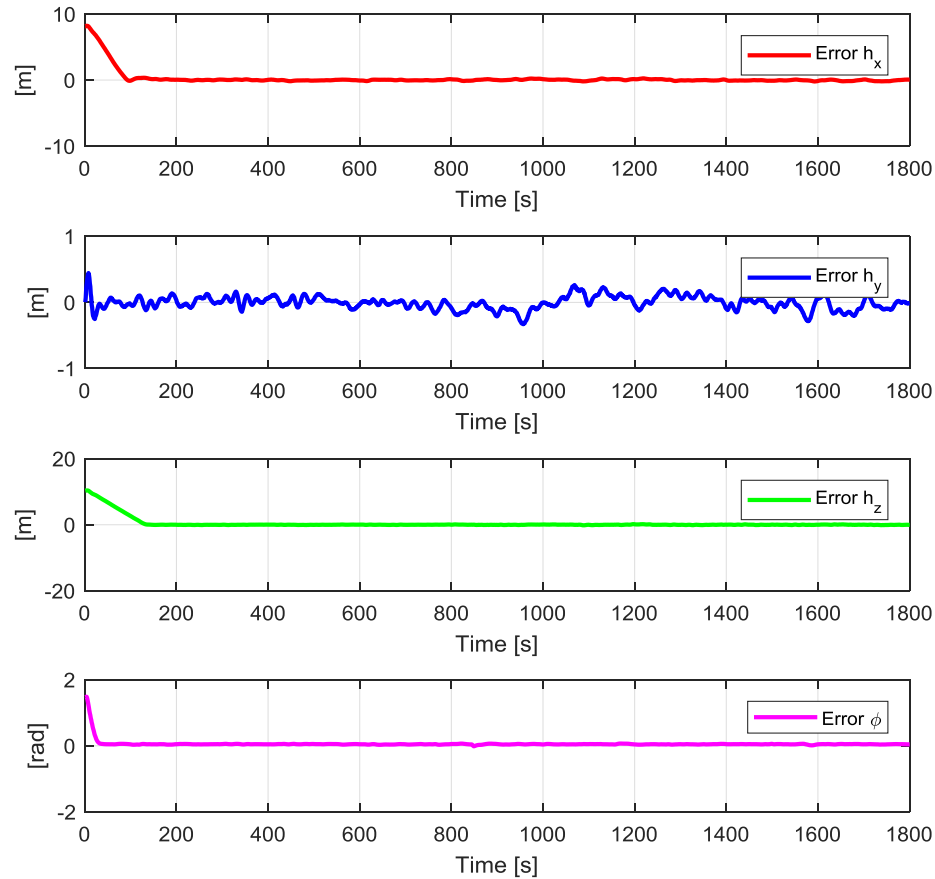
# RESULTADOS OBTENIDOS



## DESEMPEÑO DEL MANIPULADOR AEREO

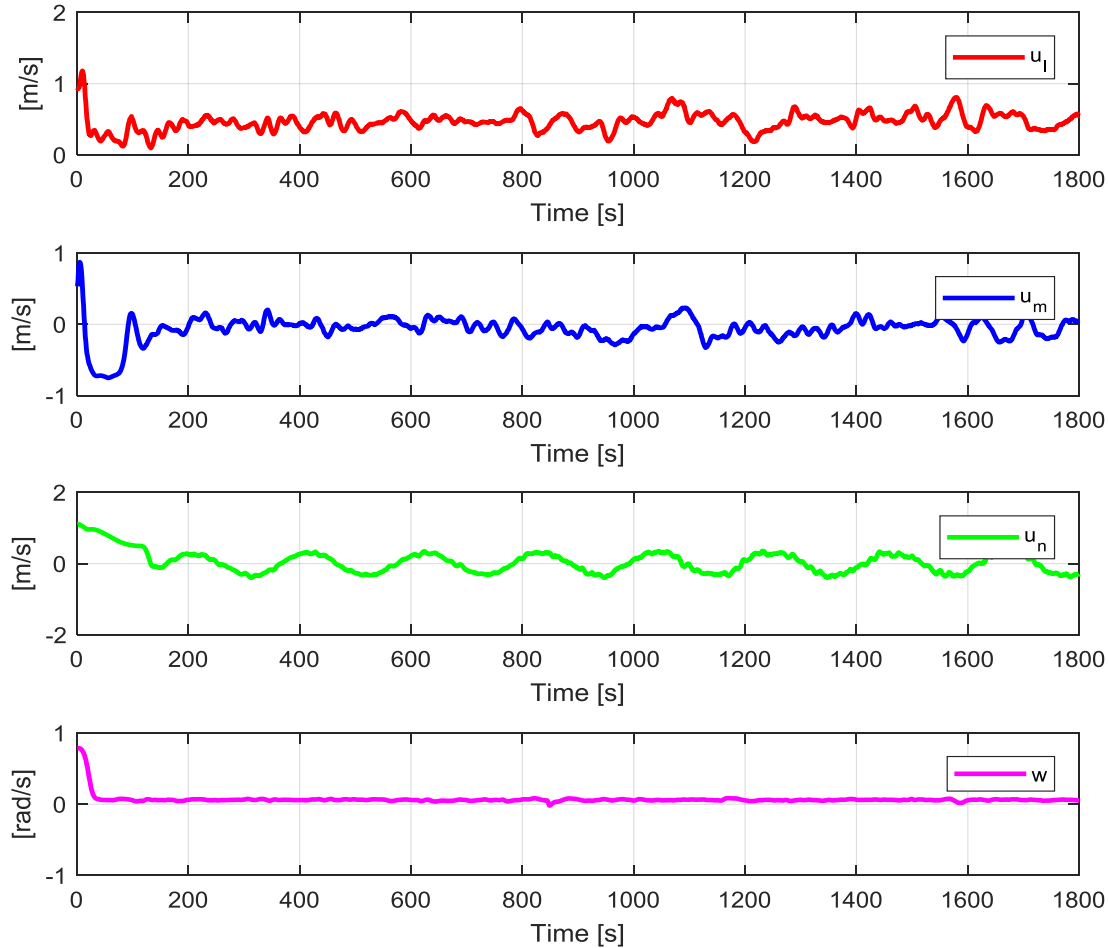


## ERROR DE POSICION DEL EFECTOR FINAL

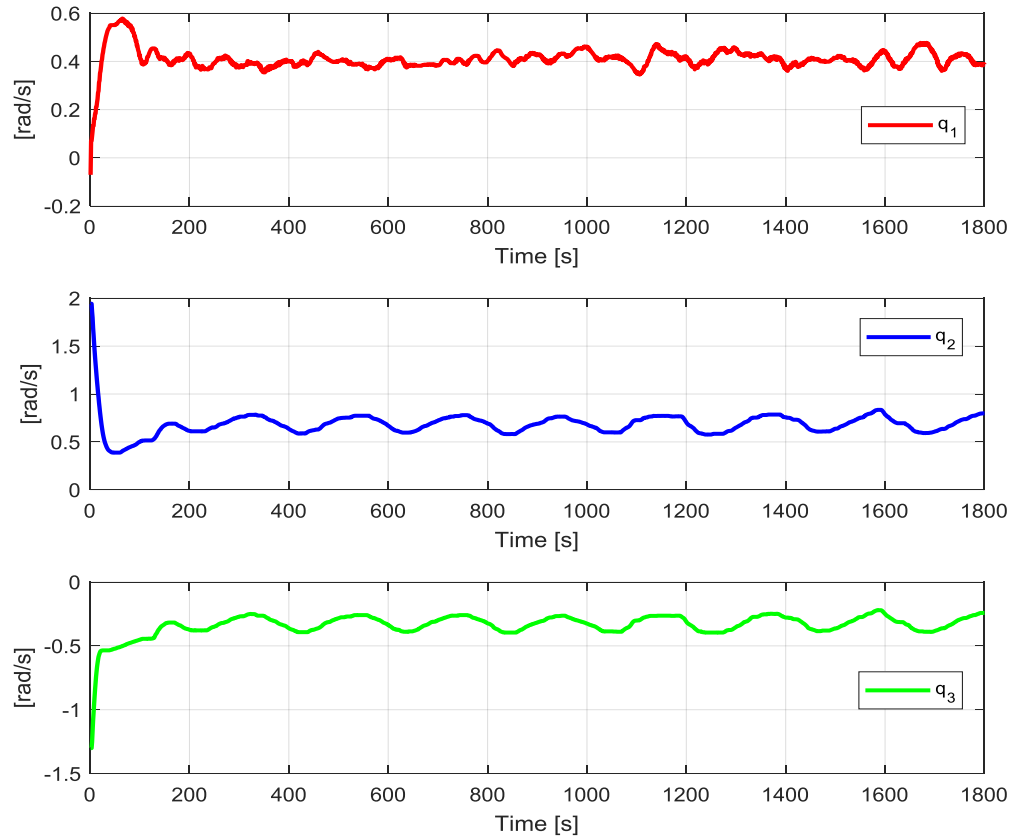




## COMANDOS DE MANIOBRABILIDAD DEL UAV



## COMANDOS DE MANIOBRABILIDAD DEL ARM





# CONCLUSIONES

- ✓ El modelo cinemático permite determinar las características de movimiento y las restricciones que puede tener el sistema robótico, para ser utilizado en los algoritmos de control, basándose en un controlador cinemático redundante.
- ✓ Por medio de una base de acoplamiento que tome en consideración las restricciones de movimiento se puede integrar otro brazo robótico al UAV sin afectar la movilidad del primer brazo.
- ✓ Mediante la teoría de Lyapunov se realizó el análisis de estabilidad del sistema demostrando que los errores de control convergen a cero, siendo asintóticamente estable.
- ✓ La comunicación RS-485 permite agregar más brazos robóticos o más grados de libertad a los brazos robóticos, permitiendo así la modularidad del UAV.
- ✓ Con la utilización de reguladores de voltaje y corriente instalados en el UAV se garantiza que los brazos robóticos y la computadora a bordo del UAV no sufran daños eléctricos



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