

Communications-aware control enabled by full pose regulation

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Half-day Tutorial Session at ICUAS 2026 (09:00 – 13:00), 15th June 2026
Room Calypso A – Divani Corfu Palace

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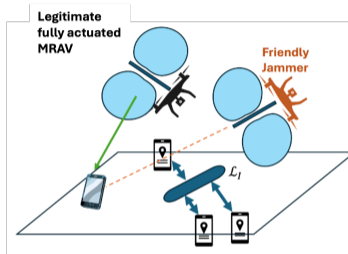
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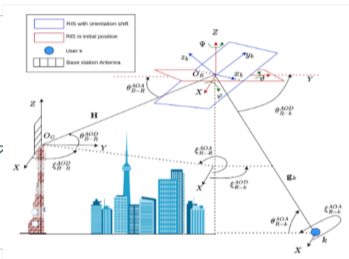
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Full pose enabled UAV communications



Physical Layer Security



Aerial RIS 3D Pose



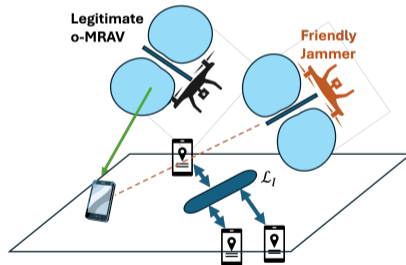
Free Space Optical Communications

Physical Layer Security

Pose aware MRAVs for Physical Layer Security: Objective

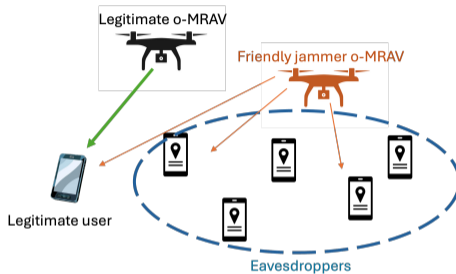
Objective

The focus of this research is to study the performance of **f-MRAVs** for **physical layer security**. Our objective is **the joint optimization** of both **position** and **orientation** to ensure **secure** communications in the presence of **eavesdroppers** [1]



[1] D. Bonilla Licea, et al., “*Harnessing the Potential of Omnidirectional Multi-Rotor Aerial Vehicles in Cooperative Jamming Against Eavesdropping*”, IEEE GLOBECOM, pp. 2052–2058, 2024.

Pose aware MRAVs for Physical Layer Security: System Model (I)



- One MRAV (MRV-I) communicates with a ground node.
- A set of N **eavesdroppers**.
- Another MRV (MRV-J) that protects the privacy of communication by **jamming** eavesdroppers in the region.

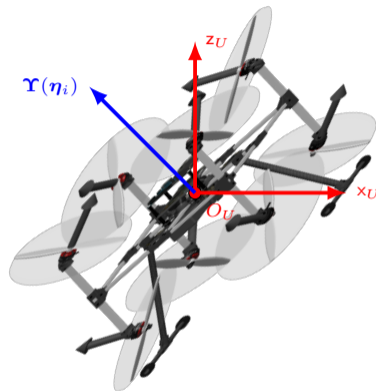
The radiation pattern of the o-MRAV antenna is:

$$G(\gamma) = \sin^2(\gamma),$$

where γ is the AoD.

We can formulate the antenna channel gains for the signals received by the node S_i as:

$$G(\gamma_{ji}) = 1 - \left\langle \frac{\mathbf{p}_{S_j} - \mathbf{p}_{U_i}}{\|\mathbf{p}_{S_j} - \mathbf{p}_{U_i}\|}, \Upsilon(\boldsymbol{\eta}_i) \right\rangle^2.$$



Orientation of the f-MRAV. The null of the antenna radiation pattern is aligned with $\Upsilon(\boldsymbol{\eta}_i)$.

Pose aware MRAsVs for Physical Layer Security: System Model (III)

- We assume that the **air-to-ground** channel is mainly influenced by path loss.
- The distance between MRAsV- i and node S_j is $d_{ij} \triangleq \|\mathbf{p}_{S_j} - \mathbf{p}_{U_i}\|$.
- The Signal to Interference and Noise Ratio (SINR) at node S_j is:

$$\Gamma_j = \frac{G(\gamma_{Ij})P_I d_{Ij}^{-2}}{G(\gamma_{Jj})P_J d_{Jj}^{-2} + \sigma_j^2}, \quad \forall j \in \{0, \dots, N\},$$

where P_i is the transmit power of MRAsV- i , and σ_j^2 is the variance of additive white Gaussian noise of node j .

- The **secrecy rate** is given by

$$R(\Gamma) = B \left[\log_2(1 + \Gamma_0) - \max_{j \in \{1, \dots, N\}} (\log_2(1 + \Gamma_j)) \right]^+,$$

where $[\cdot]^+ = \max(0, \cdot)$, B represents the allocated bandwidth.

This problem is stated as follows:

$$\begin{aligned} & \underset{\boldsymbol{\eta}_I^d, \mathbf{p}_{U_I}, \boldsymbol{\eta}_J^d, \mathbf{p}_{U_J}, P_I, P_J}{\text{maximize}} && \mathbb{E}[R(\boldsymbol{\Gamma})] \\ & \text{s.t.} && \underline{z} \leq \mathbf{e}_3^\top \mathbf{p}_{U_i} \leq \bar{z}, \\ & && \left\| \begin{bmatrix} \mathbf{I}_2 & \\ & 0 \end{bmatrix} \boldsymbol{\eta}_i \right\|_\infty \leq \frac{\pi}{2}, \\ & && 0 \leq P_i \leq \bar{P}, \end{aligned}$$

- We tackle the optimization problem in **three distinct phases** which are executed iteratively: **MRAs-I orientation**, **MRAs-J orientation**, jointly **control power and position**.

Pose aware MRAVs for Physical Layer Security

Proposed Approach: Orientation of MRAV-*I*

- **MRAV-*I* orientation** — steer max gain toward the user; maximise angular separation from eavesdroppers
- **MRAV-*J* orientation (jammer)** — lock antenna null onto the legitimate user to suppress self-interference
- **Power & position optimisation** — interior-point search for optimal 3D positions and transmission powers

Pose aware MRAVs for Physical Layer Security

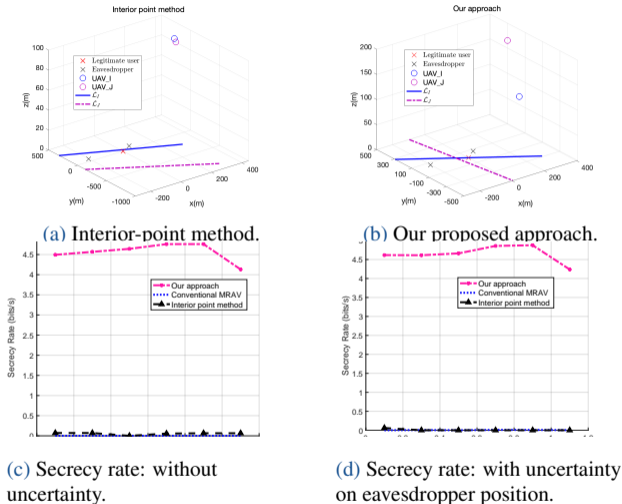


Figure: Top: final 3D positions for 2 eavesdroppers. Bottom: secrecy rate vs. maximum power. Simulations are for a scenario of a legitimate user at origin, 2 randomly placed eavesdroppers, MRAV altitudes $z \in [80, 300]$ m.

Free space optical communications

Problem Statement

THE IDEA: An heterogeneous robotic network for power infrastructure inspection.

- Multi-Rotor Aerial Vehicles (MRAVs) with body-fixed optical transmitters collect data; Unmanned Ground Vehicles (UGVs) with optical receivers act as relays to a remote station.
- A valid Free-Space Optical (FSO) link requires the MRAV beam to stay inside the receiver's cone.
- Link quality depends on MRAV position, orientation, and distance.



Problem Statement

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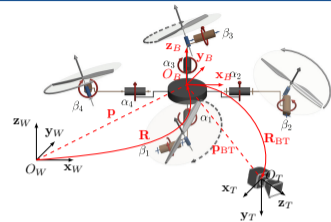


KEY CHALLENGE: Reliable FSO communication demands precise alignment, valid range, and adaptation to dynamic motion.

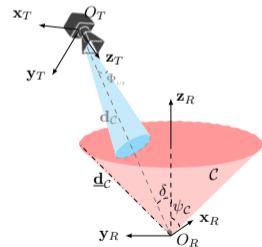
Proposed Approach

A Nonlinear Model Predictive Control (NMPC) framework that integrates FSO communication constraints into MRAV motion planning.

- (i) Model MRAV as a Generically-Tilted Multi-Rotor, covering both coplanar and tilted platforms.
- (ii) Embed FSO constraints directly into NMPC:
 - Beam alignment within receiver cone.
 - Valid communication distance ensuring minimum bit rate.
- (iii) Enforce actuator limits and obstacle avoidance.
- (iv) Achieve simultaneous tracking, communication reliability, and safety.



GTMR model (coplanar vs tilted)

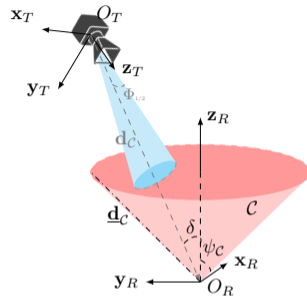
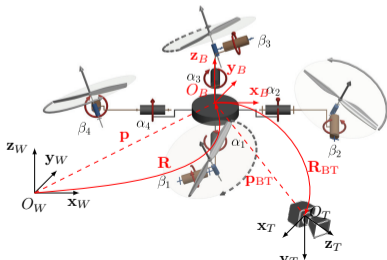


FSO link geometry (beam and receiver cone)

GTMR Dynamics

$$\begin{cases} \dot{\mathbf{p}} = \mathbf{v} \\ \dot{\boldsymbol{\eta}} = \mathbf{T}(\boldsymbol{\eta})\boldsymbol{\omega} \\ m\dot{\mathbf{v}} = -mge_3 + \mathbf{R}(\boldsymbol{\eta})\mathbf{F}(\boldsymbol{\alpha}, \boldsymbol{\beta})\mathbf{u} \\ \mathbf{J}\dot{\boldsymbol{\omega}} = -\boldsymbol{\omega} \times \mathbf{J}\boldsymbol{\omega} + \mathbf{M}(\boldsymbol{\alpha}, \boldsymbol{\beta})\mathbf{u} \end{cases}$$

\mathbf{p} : position; \mathbf{v} : velocity; $\boldsymbol{\eta}$: attitude; $\boldsymbol{\omega}$: angular rates; \mathbf{u} : rotor thrusts; $\{\mathbf{T}, \mathbf{M}\}$: allocation matrices; $\{\mathbf{R}, \mathbf{T}\}$: rotations; $\{\boldsymbol{\alpha}, \boldsymbol{\beta}\}$: tilting angles.



FSO Communication Constraints

$$\mathbf{d}_c = \mathbf{p} - \mathbf{p}_R$$

$$\mathbf{z}_T^T(-\mathbf{d}_c)/\|\mathbf{d}_c\| \geq \cos(\psi_c), \quad \underline{d}_c \leq \|\mathbf{d}_c\| \leq \bar{d}_c$$

\mathbf{z}_T : transmitter axis; \mathbf{d}_c : displacement; ψ_c : cone aperture.

Optimal Control Problem

$$\underset{\bar{\mathbf{x}}, \bar{\mathbf{u}}, \boldsymbol{\varepsilon}}{\text{minimize}} \quad \sum_{k=0}^N \|\mathbf{y}_{d,k} - \mathbf{y}_k\|_{\mathbf{Q}}^2 + \|\bar{\mathbf{u}}_k\|_{\mathbf{Q}_{\bar{\mathbf{u}}}}^2 + \|\boldsymbol{\varepsilon}_k\|_{\mathbf{Q}_{\boldsymbol{\varepsilon}}}^2 \quad (2a)$$

$$\text{s.t.} \quad \bar{\mathbf{x}}_0 = \bar{\mathbf{x}}(t_0), \quad (2b)$$

$$\bar{\mathbf{x}}_{k+1} = f(\bar{\mathbf{x}}_k, \bar{\mathbf{u}}_k), \quad k = \{0, \dots, N-1\}, \quad (2c)$$

$$\mathbf{y}_k = h(\bar{\mathbf{x}}_k, \bar{\mathbf{u}}_k), \quad k = \{0, \dots, N\}, \quad (2d)$$

$$\underline{\gamma} \leq \mathbf{u}_k \leq \bar{\gamma}, \quad k = \{0, \dots, N-1\}, \quad (2e)$$

$$\dot{\underline{\gamma}} \leq \dot{\mathbf{u}}_k \leq \dot{\bar{\gamma}}, \quad k = \{0, \dots, N\}, \quad (2f)$$

$$\underline{d}_c \leq \|\mathbf{d}_{c_k}\| \leq \bar{d}_c, \quad k = \{0, \dots, N\}, \quad (2g)$$

$$\frac{\mathbf{z}_T^\top(-\mathbf{d}_{c_k})}{\|\mathbf{d}_{c_k}\|} \geq \cos(\psi_c), \quad k = \{0, \dots, N\}, \quad (2h)$$

$$\|\mathbf{p}_k - \mathbf{p}_{\mathcal{O}_{j,k}}\|^2 \geq d_{\mathcal{O}_j} + d_{\text{safe}} - \varepsilon_{j,k}, \quad (2i)$$

$$\varepsilon_{j,k} \geq 0, \quad j = \{1, \dots, N_{\mathcal{O}}\},$$

OBJECTIVE FUNCTION: Minimize a weighted sum (2a) of tracking error, control effort, and slack penalties for obstacle avoidance.

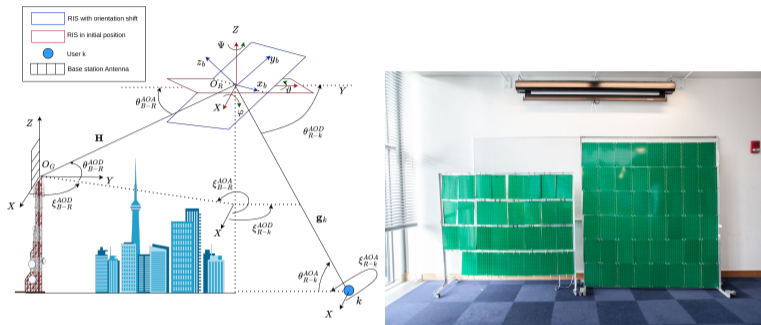
SYSTEM CONSTRAINTS: Enforce the vehicle's nonlinear dynamics (2b)–(2c) and physical limits on rotor thrusts (2f) and their rates of change (2f).

FSO COMMUNICATION CONSTRAINTS: Maintain a reliable link by enforcing constraints on the distance to the receiver (2g) and the beam's angular alignment (2h).

SAFETY CONSTRAINTS: Guarantee collision avoidance (2i) by enforcing a minimum safety distance, using slack variables to ensure feasibility in tight spaces.

RIS enabled wireless networks

Pose aware MRAsVs for RIS-Enabled Wireless Networks



- To describe its orientation, we use Euler angles with XYZ convention: roll (φ), pitch (ϑ), and yaw (ψ).
- The orientation of the fully actuated MRAsV is represented as a vector $\mathbf{\Omega} = [\varphi, \vartheta, \psi]^T \in \mathbb{R}^3$

A. Saliyah, et, "Harnessing the Potential of Omnidirectional UAVs in RIS-Enabled Wireless Networks," ICASSP 2025.

- The data rate of a given user k is defined by

$$R_k = B_k \log_2 \left(1 + \frac{P_0 G_A |\mathbf{g}_k \mathbf{M}_\Theta \mathbf{H} \mathbf{f}|^2}{\sigma_0^2} \right), \forall k \in \mathcal{K},$$

with

$$\mathbf{H} = \eta_{B-R} \mathbf{a}_{rx,R}(\theta_{B-R}^{AOA}, \xi_{B-R}^{AOA}, \boldsymbol{\Omega}) \mathbf{a}_{tx,B}^*(\theta_{B-R}^{AOD}, \xi_{B-R}^{AOD}),$$

$$\mathbf{g}_k = \eta_{R-k} \mathbf{a}_{tx,R}^*(\theta_{R-k}^{AOD}, \xi_{R-k}^{AOD}, \boldsymbol{\Omega}),$$

$$\mathbf{M}_\Theta = \text{diag}(\{e^{j\theta_i}\}_{i=1}^M)$$

Pose aware MRAsVs for RIS-Enabled Wireless Networks

Problem Formulation

$$\begin{aligned} \max_{\Omega, \mathbf{p}_R, \Theta} & \quad \left(\min_{k \in \mathcal{K}} R_k \right) \\ \text{s.t.} & \quad \varphi \in \left[0, \frac{\pi}{2} \right], \vartheta \in \left[0, \frac{\pi}{2} \right], \psi \in [0, 2\pi), \\ & \quad \theta_m \in [0, 2\pi], \forall m \in \mathcal{M}, \\ & \quad \mathbf{p}_R^T \in [x_{\min}, x_{\max}] \times [y_{\min}, y_{\max}] \times [z_{\min}, z_{\max}]. \end{aligned} \tag{3}$$

- This problem is **non-concave** with a **non-smooth** objective function because of the min function.
- We first approximate the min function using the **p -norm**, which provides a close approximation when $p \rightarrow -\infty$, $\|(R_1, \dots, R_K)\|_p$.

Pose aware MRAs for RIS-Enabled Wireless Networks

Parallel Successive Convex Approximation

Problem: Let $\mathcal{X} = \mathcal{X}_1 \times \mathcal{X}_2 \times \mathcal{X}_3$, where $\mathcal{X}_1 = [0, 2\pi]^M$, $\mathcal{X}_2 = [x_{\min}, x_{\max}] \times [y_{\min}, y_{\max}] \times [z_{\min}, z_{\max}]$, $\mathcal{X}_3 = [0, \frac{\pi}{2}]^2 \times [0, 2\pi]$:

$$\min_{\mathbf{x}_i \in \mathcal{X}_i, \forall i} F(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3) = -\|(R_1, \dots, R_K)\|_p$$

PSCA (Parallel Successive Convex Approximation) solves convex subproblems in parallel at each iteration l :

$$\hat{\mathbf{x}}_i(\mathbf{x}^l) = \arg \min_{\mathbf{x}_i \in \mathcal{X}_i} \tilde{F}_i(\mathbf{x}_i | \mathbf{x}^l), \quad \forall i \in \{1, 2, 3\}$$

where $\tilde{F}_i(\mathbf{x}_i | \mathbf{x}^l)$ is the first-order Taylor expansion of F around \mathbf{x}^l w.r.t. \mathbf{x}_i .

Update rule (repeated until convergence):

$$\mathbf{x}^{l+1} = \mathbf{x}^l + \gamma^l (\hat{\mathbf{x}}(\mathbf{x}^l) - \mathbf{x}^l)$$

Pose aware MRAsVs for RIS-Enabled Wireless Networks

Simulation Results (1/2)

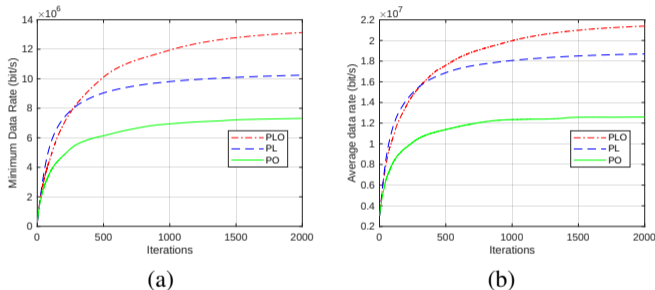
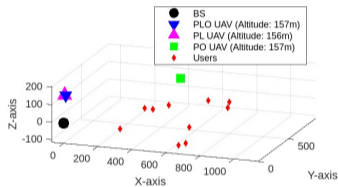


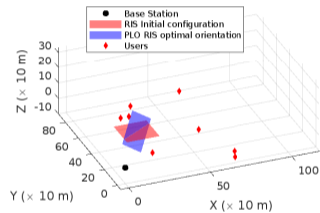
Figure: (a) Minimum rate vs iterations, (b) Average rate vs iterations.

Pose aware MRAs for RIS-Enabled Wireless Networks

Simulation Results (2/2)



(a)



(b)

Figure: (a) Optimized positions of fully actuated MRAs, (b) Optimal RIS orientation for PLO.

Key Takeaways

Main Message

Full-pose controllable MRVs enable communication-aware control,
allowing communication performance to be optimized through both *position* and *orientation*.

Highlights

- Full-pose regulation introduces **new degrees of freedom** for wireless communications.
- Communication metrics can be directly incorporated into motion planning and control.
- Applications include:
 - Physical Layer Security
 - RIS-assisted communications
 - Free-Space Optical communications
- **Joint optimization** of mobility, orientation, and communication resources leads to significant performance gains.
- Communication-aware aerial robotics represents a promising direction toward autonomous 6G-enabled aerial networks.

Mobility + Orientation + Communications



D. Bonilla Licea, G. Silano, M. Ghogho, and M. Saska

Optimum Trajectory Planning for Multi-Rotor UAV Relays with Tilt and Antenna Orientation Variations

European Signal Processing Conference, 1586–1590, 2021



D. Bonilla Licea, G. Silano, H. El Hammouti, M. Ghogho, and M. Saska

Reshaping UAV-Enabled Communications with Omnidirectional Multi-Rotor Aerial Vehicles

IEEE Communications Magazine, 63(5), 94–100, 2025



G. Silano, D. Bonilla Licea, H. El Hammouti, and M. Saska

Free-Space Optical Communication-Driven NMPC Framework for Multi-Rotor Aerial Vehicles in Structured Inspection Scenarios

IEEE International Conference on Systems, Man, and Cybernetics, 2025

Thank you

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