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Optimized PID Control for Trajectory Tracking of an Unmanned Ground Vehicle in a Virtual Environment

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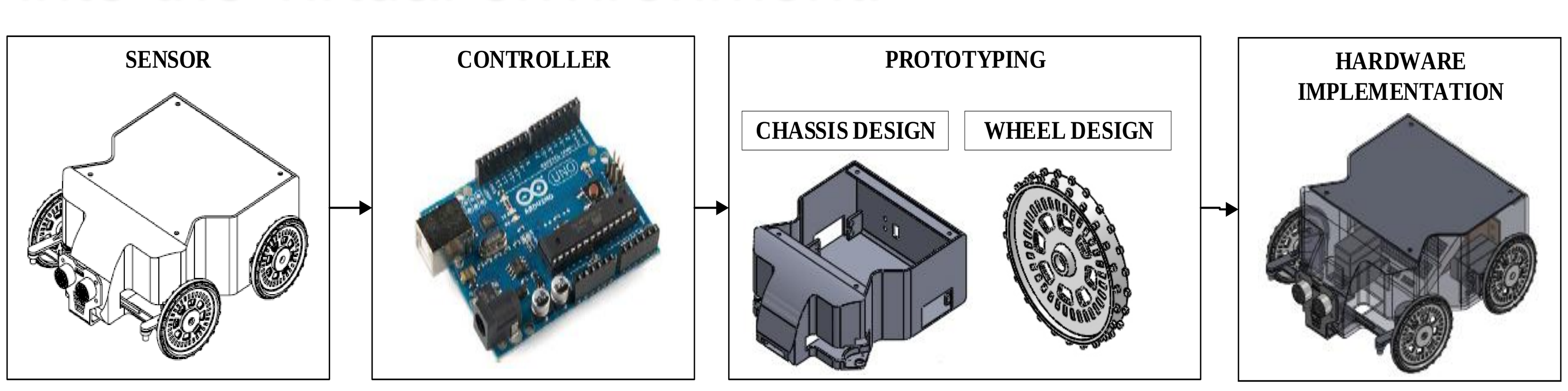
INTRODUCTION & AIM

Unmanned Vehicles (UVs) are intelligent vehicles that use sensors to perceive their environment and plan optimal paths (Lamini et al., 2018). Among them, Unmanned Ground Vehicles (UGVs) operate on land and face energy constraints during obstacle navigation (Jabbarpour et al., 2017). Efficient path planning and control are therefore essential. The PID controller remains popular for its simplicity, though its performance depends on optimal tuning of Kp, Ki, and Kd parameters. This study employs the Walrus Optimizer (WO), a recent swarm-based algorithm inspired by walrus behavior (Han et al., 2024), to enhance PID parameter tuning, an area yet to be explored.

METHOD

A 3D model of the UGV was designed using Autodesk 123D modeling software and imported into the virtual environment.



Control Problem: Given a desired trajectory $q_d(t)$, the objective is to design a control law that drives the tracking error $q_e(t) = q_d(t) - q(t)$ to zero as $t \longrightarrow \infty$ such that $q_d(t) = q(t)$.

$$u = K_p q_e(t) + K_i \int q_e(t)dt + K_d \frac{dq_e(t)}{dt} \qquad (1)$$

Optimization Problem (PID Tuning): Given the desired trajectory $q_d(t)$ and the actual output $q(t)$, find the optimal PID gains $k = [k_p, k_i, k_d]$ that minimize the tracking error and ensure stable system response. The objective is:

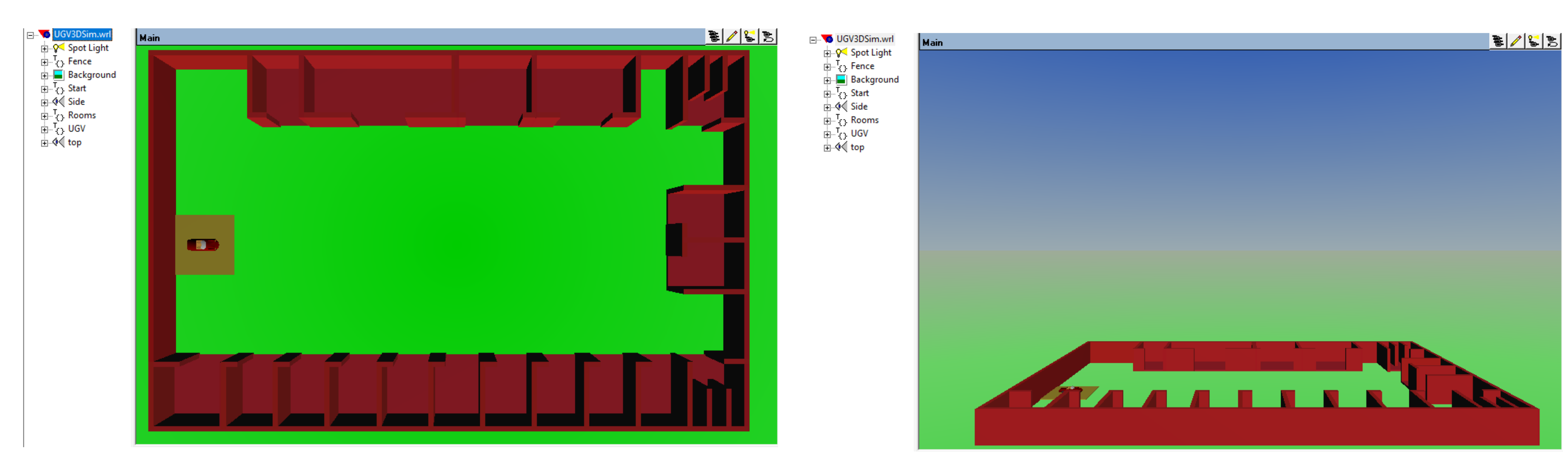
$$\min_{k_p,k_i,k_d} J = \int_0^T q_e^2(t)dt\,, q_e(t) = \begin{bmatrix} x_d - x \\ y_d - y \\ \theta_d - \theta \end{bmatrix} \qquad (2)$$

RESULTS & DISCUSSION

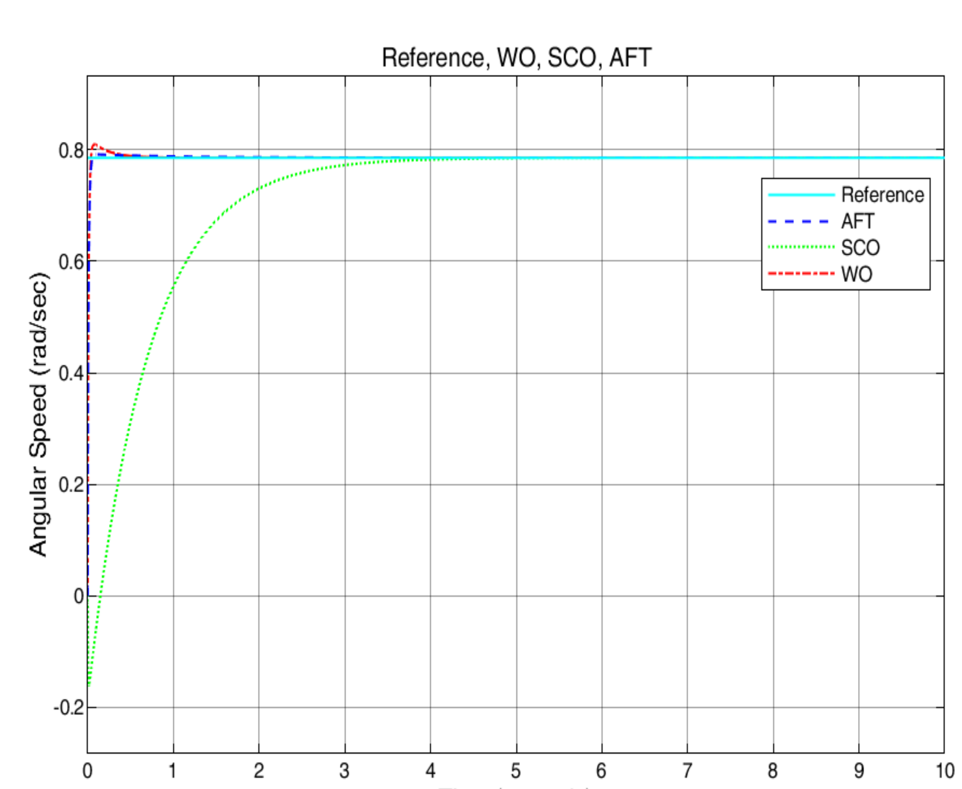
Optimized PID Parameters

Optimization Technique	PID Controller Parameters		
	K_p	K_i	K_d
AFT	1.9998	1.9139	0.0000
WO	1.9998	9.3411	7.5516e-07
SCO	6.5201	9.3411	7.5516e-07

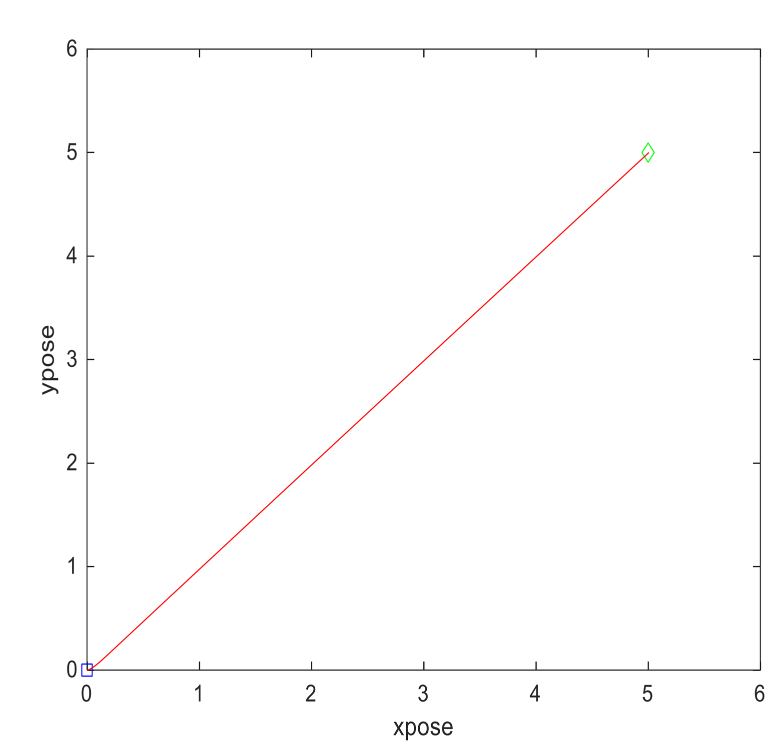
UGV3DSim Simulation Environment



Performance of PID controllers optimized using AFT, WO, and SCO



Angular Speed (0.8 rad/s)



Linear Path Tracking

CONCLUSION

In conclusion, the WO-based PID controller demonstrated superior trajectory tracking accuracy and stability, effectively minimizing errors across various motion paths.

FUTURE WORK / REFERENCES