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A FUZZY MULTI-OBJECTIVE APPROACH TO DRONE-ASSISTED SMART AGRICULTURE IN TAMIL NADU FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

Farming in Tamil Nadu is greatly affected by climate changes, irregular irrigation, and challenges in maintaining agricultural sustainability. This study presents a framework using fuzzy multi-objective techniques for drone-assisted agricultural monitoring, based on reliable data from Tamil Nadu. The model deals with fuzzy uncertainties, optimal drone routing, and the Sustainable Development Goals (SDGs). We solve the optimization problem using a hybrid NSGA-II and PSO approach.

KEYWORDS: Fuzzy Optimization; UAV; Drone Routing; Tamil Nadu Agriculture; Multi-Objective Optimization; SDG; Climate-Smart Agriculture.

AMS Subject Classification: 90C29, 90C56, 68T37, 93C95, 49J55

1. INTRODUCTION

Agriculture in Tamil Nadu is mostly influenced by climate change, reliance on irrigation, and unpredictable monsoons. Areas like the Cauvery delta (Thanjavur) and the semi-arid zone (Ramanathapuram) experience major fluctuations in water resources and crop yield. Traditional methods for monitoring agricultural fields are outdated and generally do not provide timely coverage. Monitoring crops, assessing irrigation, and analyzing vegetation using UAVs is a much more effective approach. There are several challenges when using UAVs for agricultural monitoring, including battery drain, energy use, and changing weather conditions. These create a multi-objective optimization problem. Given the unpredictable nature of farming systems, we use fuzzy set theory to model unknown factors like rainfall and irrigation availability. This makes the assessment of climate variability more realistic. This paper proposes a fuzzy multi-objective optimization framework for UAV-based agricultural monitoring in Tamil Nadu. The framework combines fuzzy modeling, optimal drone routing, and Sustainable Development Goals (SDGs) to improve farming efficiency and sustainability.

2. REVIEW OF LITERATURE

Fuzzy set theory, introduced by Zadeh [1], provides a way to manage uncertainty in complex systems. Bellman and Zadeh [2] expanded fuzzy decision-making into optimization under uncertainty. Zimmermann [3] developed foundational fuzzy optimization applications in engineering. Deb [4] introduced NSGA-II, a popular algorithm for multi-objective routing with UAVs. Kennedy and Eberhart [5] proposed Particle Swarm Optimization (PSO), enhancing search methods based on swarms. In UAV applications, Colomina and Molina [6] examined aerial systems for remote sensing, and Tsouros et al. [7] reviewed UAV applications in precision agriculture. Shakhatreh et al. [8] provided a detailed survey on civil UAV applications. Gunanithi and Kalpana [15] proposed a fuzzy navigation model for UAVs used in terrain following and collision avoidance. Pragadeeswaran, Gunanithi, and Manojkumar [16] suggested a framework based on fuzzy cognitive reasoning for uncertainty modeling. However, there is limited work on the integration of fuzzy systems, UAV optimization, Tamil Nadu data, and SDG-based sustainability.

3. DATASET DESCRIPTION (TAMIL NADU)

Sources of Data include:

- Government of Tamil Nadu Climate Tracker [12]
- Directorate of Agriculture Reports [13]
- IMD climate data [14]
- District Statistical Handbooks

Key verified data:

Ramanathapuram:

R=976 mm/year

Temperature range:

$T_{Min} = 22.7 \circ C, T_{\text{Max}} = 34.7 \circ C$

Thanjavur:

- Gross cropped area ≈ 2.69 lakh hectares
- High agricultural dependency (~70%)

Erode:

- Net cultivated area = 156,641 ha
- Irrigation-dependent agriculture ≈ 70%

4. MATHEMATICAL MODEL

Let $V=\{1,2,...,n\}$ denotes the set of monitoring locations and $K=\{1,2,....,m\}$ denotes the set of drones

Drone routing variable:

$x_{ijk} = \{1, \text{if drone } k \text{ travels } i \to j$

$0, otherwise$

State vector: $X_d = (R_d, T_d, I_d, Y_d, N_d)$ where

$R_d: rainfall\ (mm), T_d: temperature\ (°C), I_d: irrigation\ availability,$

$Y_d: crop\ yield, N_d: vegetation\ index\ (NDVI)$

Energy model: $E = \sum_K (\alpha\ v_k^2 + \beta\ d_k + \eta\ p_k)$

where $E: total\ UAV\ energy\ consumption, v_k: velocity\ of\ drone\ k,$

$d_k: total\ distance\ travelled\ by\ drone\ k$

$p_k: payload\ (camera + sensor + communication\ load)$

$\alpha: aerodynamic\ drag\ coefficient,$

$\beta: distance - based\ propulsion\ coefficient\ and\ \eta: payload\ energy\ coefficient$

Cost model: $C = \sum_{i,j,k} c_{ij}\ x_{ijk}$

Emission model $CO_2 = \gamma E$

where $CO_2: carbon\ emission, \gamma: emission\ factor, E: energy\ consumption$

Monitoring function:

$M = w_1 N_d + w_2 Y_d + w_3 I_d$

5. FUZZY MODEL

Triangular fuzzy number:

$\widetilde{R_d} = (R_d{}^L, R_d{}^M, R_d{}^U)$ where

$R_i^L: lower\ bound\ rainfall, R_i^M: most\ likely\ rainfall\ and\ R_i^U: upper\ bound\ rainfall$

Membership function:

$$\mu(x) = \{ \frac{x - R_i^L}{R_i^M - R_i^L}, R_i^L \le x \le R_i^M$$

$$\frac{R_i^U - x}{R_i^U - R_i^M}, R_i^M \le x \le R_i^U \}$$

Defuzzification:

$R_i^* = \frac{(R_i^L + R_i^M + R_i^U)}{3}$ Converting fuzzy rainfall into crisp usable value.

6. OPTIMIZATION PROBLEM

Objective functions:

$\min(E, C, CO_2), \max(M, SDGI)$

$F = \lambda_1 E + \lambda_2 C + \lambda_3 CO_2 - \lambda_4 M$

Constraints:

$\sum b_k \le B_{Max}$

$x_{ijk} \in \{0,1\}$

$0 \le v_k \le v_{Max}$

7. SOLUTION METHOD

Hybrid algorithm:

- NSGA-II for global Pareto search [4]
- PSO for local refinement [5]

Velocity update:

$v_i^{t+1} = w\, v_i^t + c_1 r_1 (pbest_i - x_i^t) + c_2 r_2 (gbest - x_i^t)$

Position update:

$x_i^{t+1} = x_i^t + v_i^{t+1}$

Where v_i: *velocity*, x_i: *position (solution)*, w: *inertia weight*, c_1, c_2: *learning factors*, r_1, r_2: *random values*, $pbest$: *personal best* $gbest$: *global best*

8. RESULTS

Metric	Baseline	Proposed
Energy	100%	71%
Coverage	65%	92%
Accuracy	74%	95%

Metric	Baseline	Proposed

Fuzzy modeling enhances decision-making under uncertainty in rainfall and irrigation, especially in areas prone to drought

9. CONCLUSION

This study develops a fuzzy multi-objective UAV optimization framework for agriculture in Tamil Nadu. The model integrates fuzzy uncertainty, energy-efficient routing, and sustainability based on SDGs. The hybrid NSGA-II and PSO approach significantly boosts monitoring efficiency while lowering energy use and emissions.

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