The University of Texas Rio Grande Valley

Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS)

Trajectory Analysis for Congestion Detection in Foraging Robot Swarms

Arturo Gonzalez, Rodrigo Torres-Mora and Qi Lu
Department of Computer Science
The University of Texas Rio Grande Valley

Abstract

- This proposal aims to improve the efficiency of robotic swarm foraging by maximizing resource collection while minimizing collisions and congestion.
- Existing algorithms demonstrate potential efficiency but often struggle to inter-robot collisions and congestions as swarm sizes increase.
- In this study, we propose optimizing foraging behavior by analyzing congestion patterns based on robot trajectories within the swarm. Upon detecting congestion, robots will dynamically adjust their behavior to adapt and maintain optimal performance.

Introduction & Background

- Robotic swarm foraging draws inspiration from natural foraging behaviors observed in ants and other organisms. However, as the number of robots increases, collisions and congestion significantly reduce efficiency, impacting resource collection.
- This project aims to tackle these challenges using data-driven approaches and machine-learning techniques.

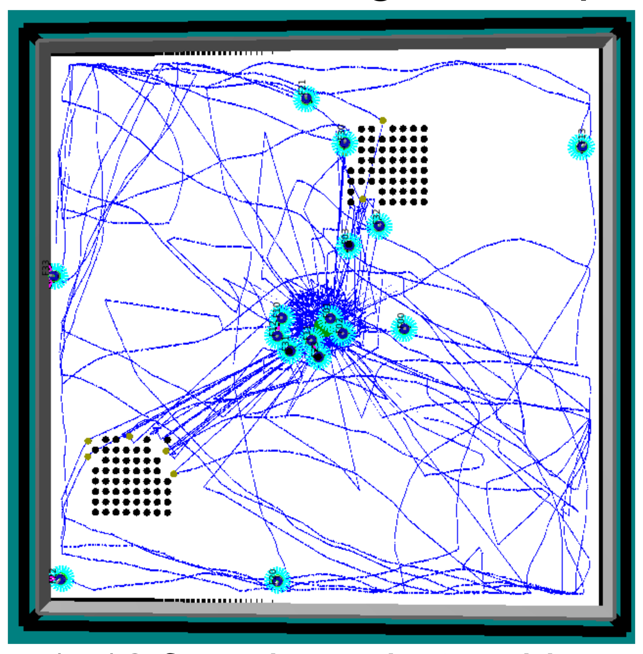

Figure 1: 16 foraging robots with congestion around center in ARGoS simulation

- Our goal is to improve and optimize a foraging algorithm during the return of resources, which in this case will increase the swarm's amount of collected resources, whilst decreasing congestion rates regarding robot foraging.

Methodology

- We track robot movement, collect data, and identify congestion zones. We segmented each robot's movement into small "trajectory windows," allowing us to analyze congestion points more precisely. Our model detects congestion based on three features: distance ratio, average velocity, and curvature.

Methodology Cont.

- These features are subject to change and experiments are still being conducted to determine which features might be more helpful in deciding congestion.
- Furthermore, since the data follows a time series approach, we also use the history of a trajectory window to determine if its congested. By training a logistic regression model, we predict congestion in real time.

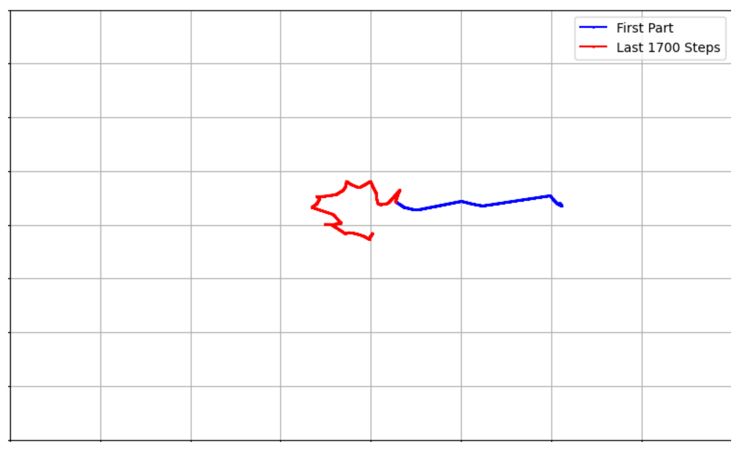

Figure 2: Trajectory with congested area highlighted

Data and Results

- We conducted 112 simulation runs, each generating complete robot trajectories. By splitting these trajectories into smaller windows, we created a dataset with over 2,900 labeled trajectory windows, each containing features that indicate congestion, such as distance ratio, average velocity, and curvature. Using 80% of this dataset for training and 20% for testing, our Logistic Regression model achieved a promising accuracy of 93.22% in distinguishing congested from non-congested windows.
- This result suggests that our model can somewhat effectively identify traffic congestion points within the swarm.

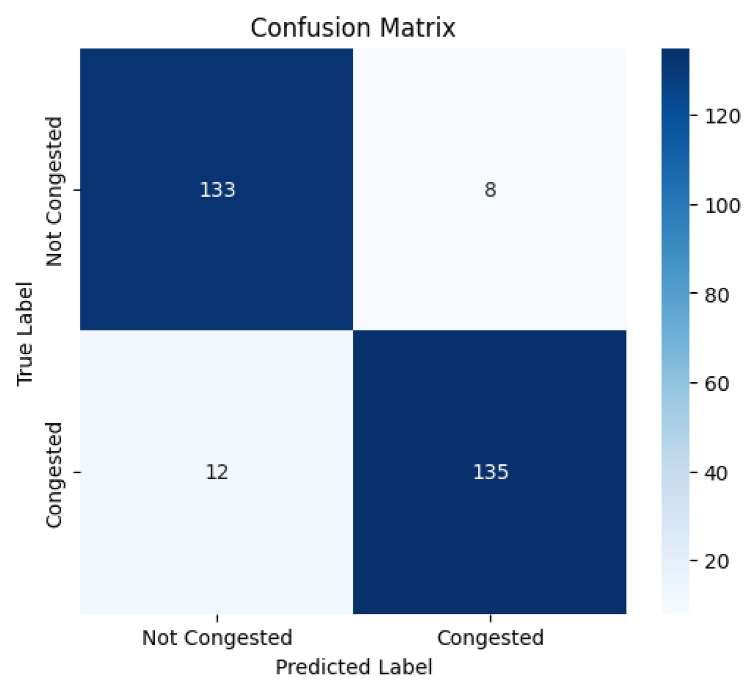

Figure 3: Accuracy of the model on predicting if a trajectory window is congested

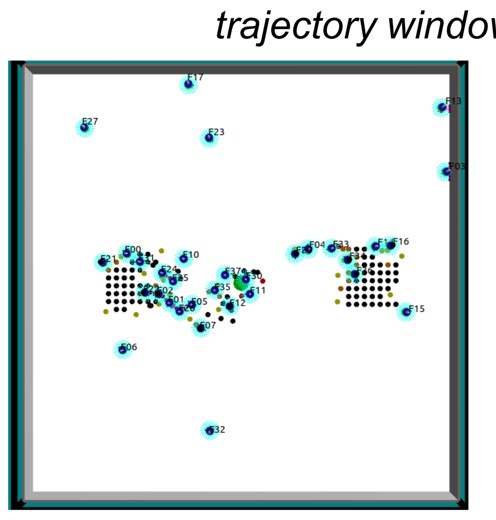

Figure 4: 32 robot simulation with congestion detection model and resource drop-off (new model)

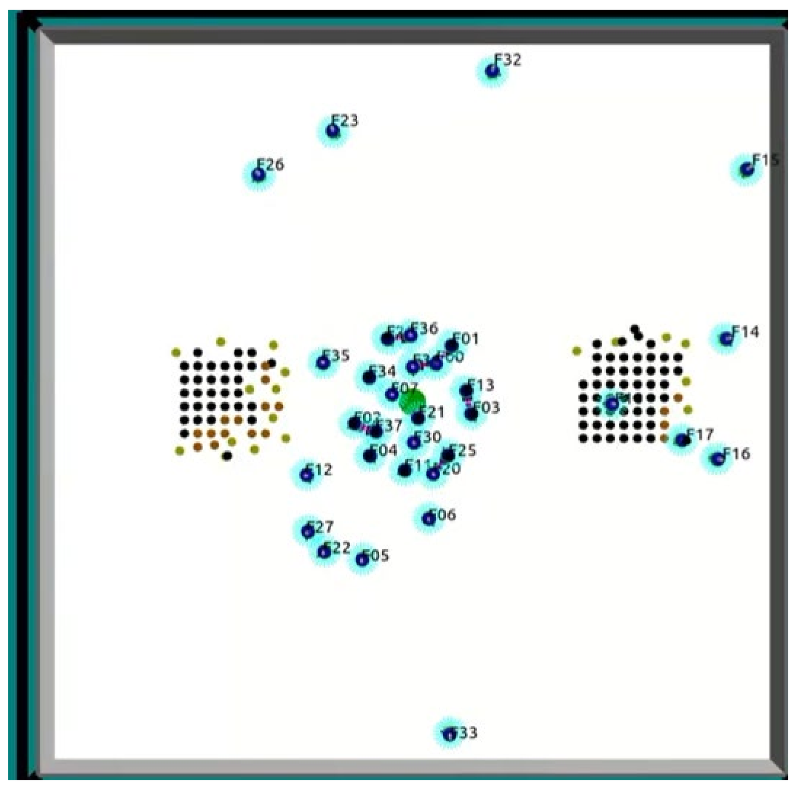

Figure 5: 32 robot simulation with no congestion detection and no resource drop-off(baseline).

Conclusions & Future Work

- The current model shows a great improvement to the baseline CPFA model. We were able to reduce the number of collisions by an average of 30%.
- Furthermore, the new trained model was able to pick up an average of 70% more resources compared to the baseline CPFA.
- Even though we were able to get a significant improvement in this two areas. The total amount resources collected and dropped off to the nest was around the same as the baseline model.
- Future work will focus on refining drop-off strategies, improving decision-making for when and where to release resources, and exploring alternative congestion mitigation techniques.

Acknowledgments

The authors would like to acknowledge funding provided by the National Science Foundation CREST Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (NSF Award No. 2112650) and the NSF Minority Serving Institute program (NSF Award No. 2318682).

References

1. Lu, Q., Moses, M. E., & Hecker, J. P. A scalable and adaptable multiple-place foraging algorithm for ant-inspired robot swarms, 2016.
2. Bharaswadkar, A., Vakilian, V., Thoms, B., & Isaacs, J. T. (2021). Congestion strategies for clustered central place foraging. IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC) (pp. 185-190), 2021.
3. Soriano Marcolino, L., Tavares dos Passos, Y., Fonseca de Souza, Á. et al. Avoiding target congestion on the navigation of robotic swarms. Autonomous Robot 41, 1297–1320, 2017.