Implicit Coordination in Robotic Swarms

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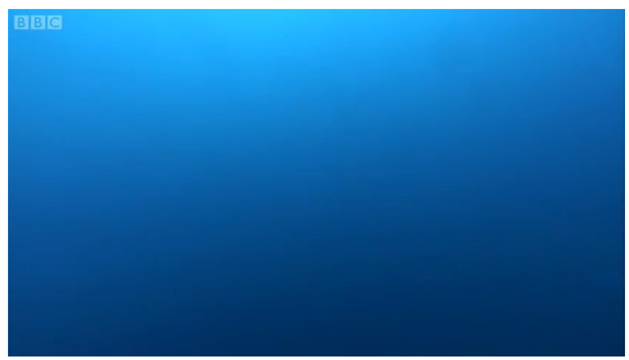
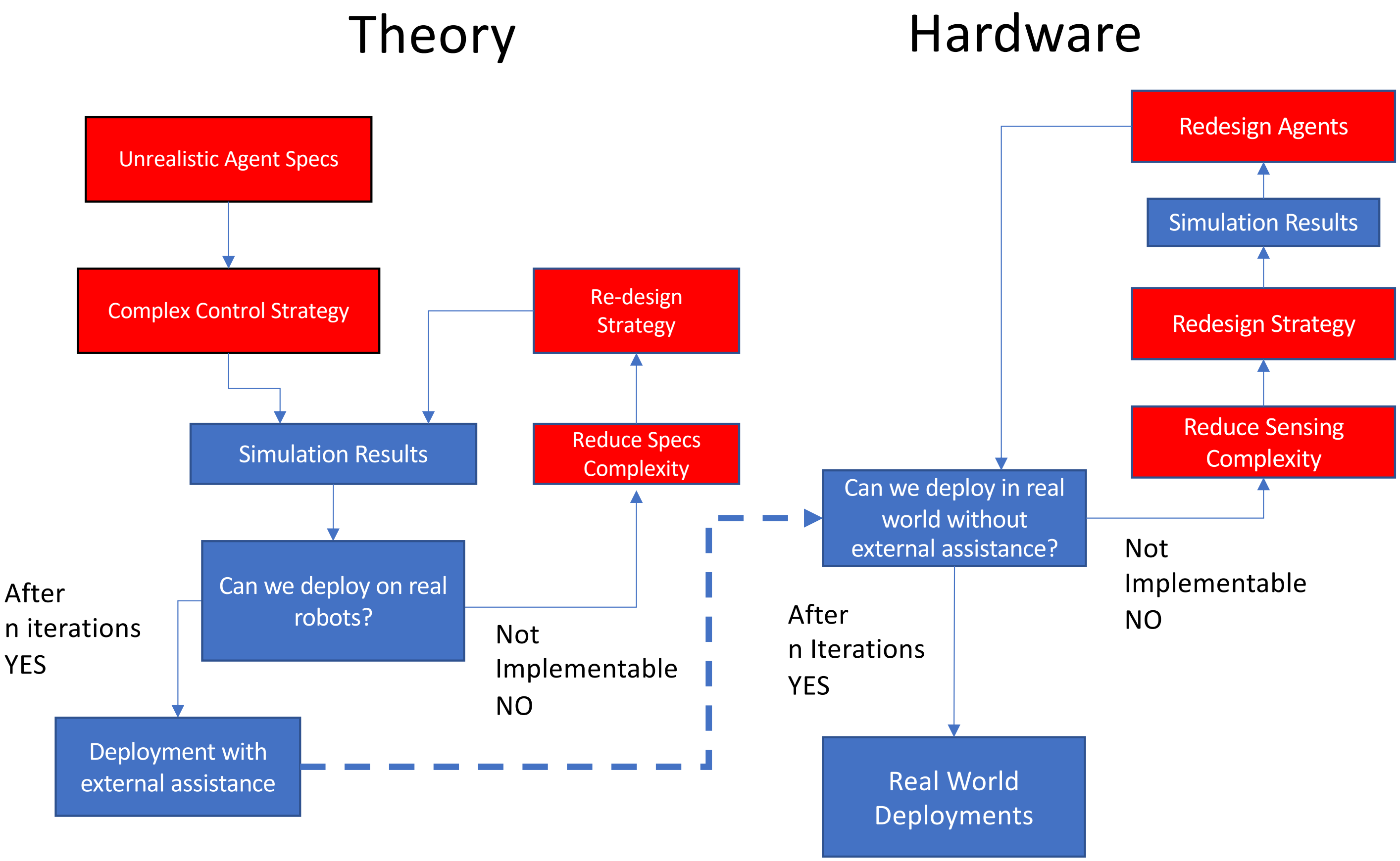
Swarms

Robotic Swarms



Natural Swarms

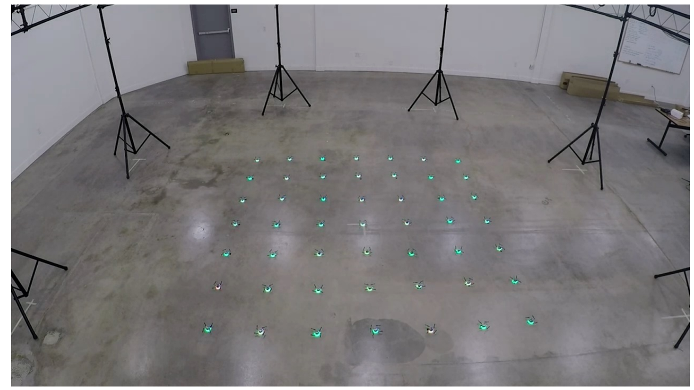
Traditional Research Method



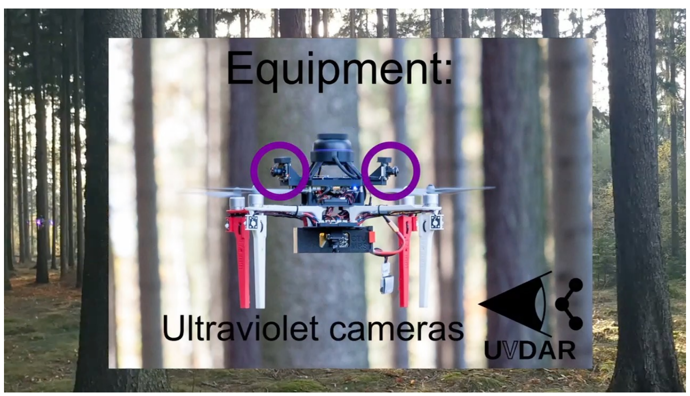
Aerial Robotic Swarms (Current State of the Art)

VIO - Swarm

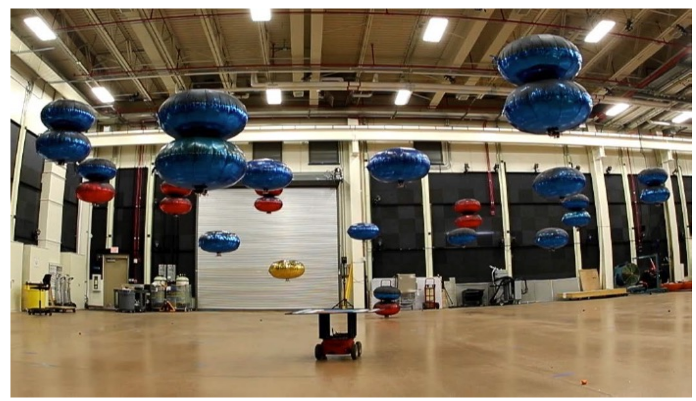
CrazySwarm



MAV - Swarm



LTA Swarm



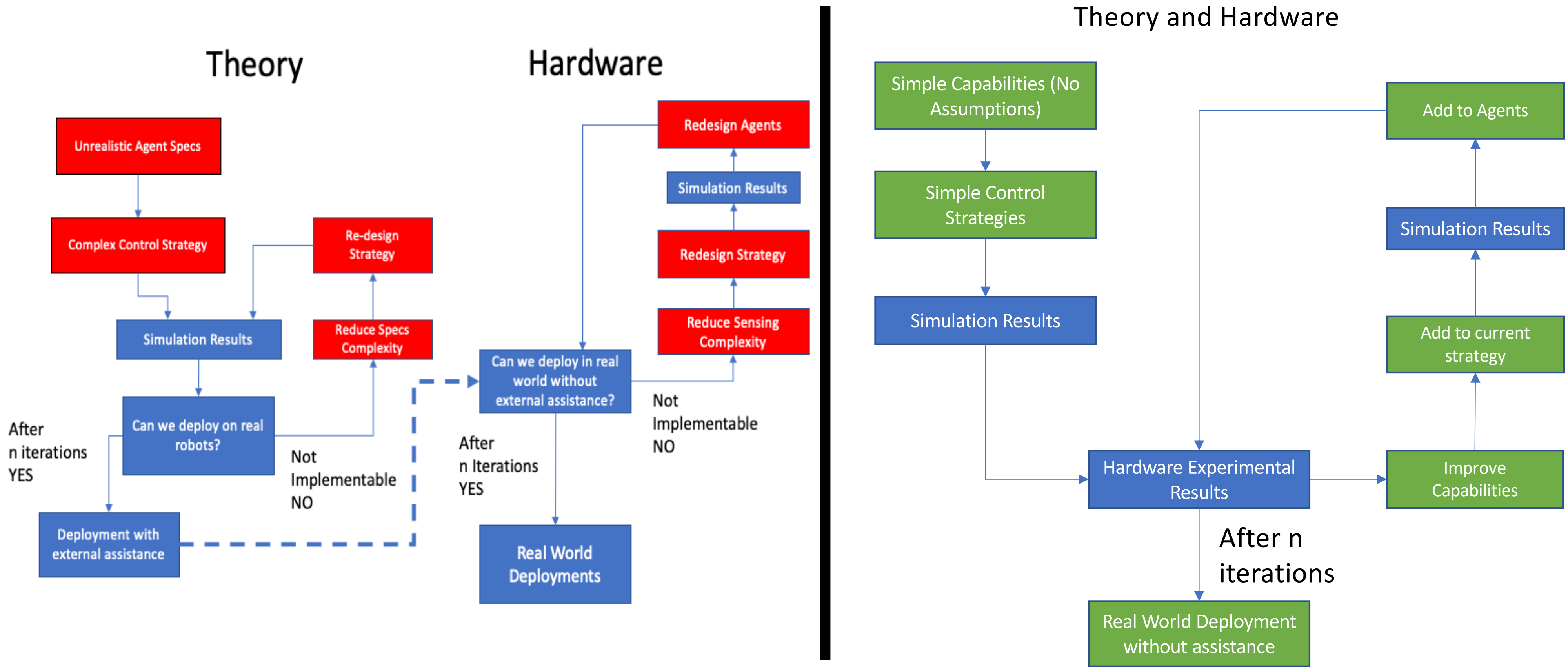
Existing Swarm Summary

Platform Name	Domain (3D)	Agent Type	Thrust To Hover	Inter Agent Comms	Coordination	System Requirements	Algorithm Requirements	High Compute Power
VIO - SWARM[6]	Aerial	Quadcopter	Required	No	Indirect	Onboard Stereo Vision, Vision, IMU, Base Station	1)Online Trajectory planning, 2)State Estimation Using dead reckoning and UKF, 3) Collision Avoidance	Yes
Crazyswarm [3]	Aeial	Quadcopter	Required	No	Indirect	Motion Capture, Base Station	1) Online trajectory planning (Piecewise and Single-piece Polynomials), 3)Positional, velocity and acceleration Data, EKF, 4)Collision avoidance	Yes
Lighter-Than-Air Swarm (LTA) [4]	Aerial	Robotic Blimps	No	No	Indirect	Motion Capture, Base Station	Positional Data, PID, Base Station	No
MAV-Swarms [5]	Aerial	Quadcopter	Required	No	Implicit	Onboard Vision, PX4Flow odometry sensory, IMU, Environmental Cues, Environmental Map	1)Vision based Relative Localization, 2)Collision Avoidance	Yes

[3] J. A. Preiss, W. Honig, G. S. Sukhatme and N. Ayanian, "Crazyswarm: A large nano-quadcopter swarm," *2017 IEEE International Conference on Robotics and Automation (ICRA)*, 2017, pp. 3299-3304, doi: 10.1109/ICRA.2017.7989376.
[4] Schuler, Tristan & Lofaro, Daniel & Mcguire, Loy & Schroer, Alexandra & Lin, Tony & Sofge, Donald. (2019). A Study of Robotic Swarms and Emergent Behaviors using 25+ Real-World Lighter-Than-Air Autonomous Agents (LTA 3). 10.13140/RG.2.2.11155.20001.
[5] M. Saska, "MAV-swarms: Unmanned aerial vehicles stabilized along a given path using onboard relative localization," *2015 International Conference on Unmanned Aircraft Systems (ICUAS)*, 2015, pp. 894-903, doi: 10.1109/ICUAS.2015.7152376.
[6] A. Weinstein, A. Cho, G. Loianno and V. Kumar, "Visual Inertial Odometry Swarm: An Autonomous Swarm of Vision-Based Quadrotors," in *IEEE Robotics and Automation Letters*, vol. 3, no. 3, pp. 1801-1807, July 2018, doi: 10.1109/LRA.2018.2800119.

Green – Desired
Red – Deal Breaker

Proposed Research Method

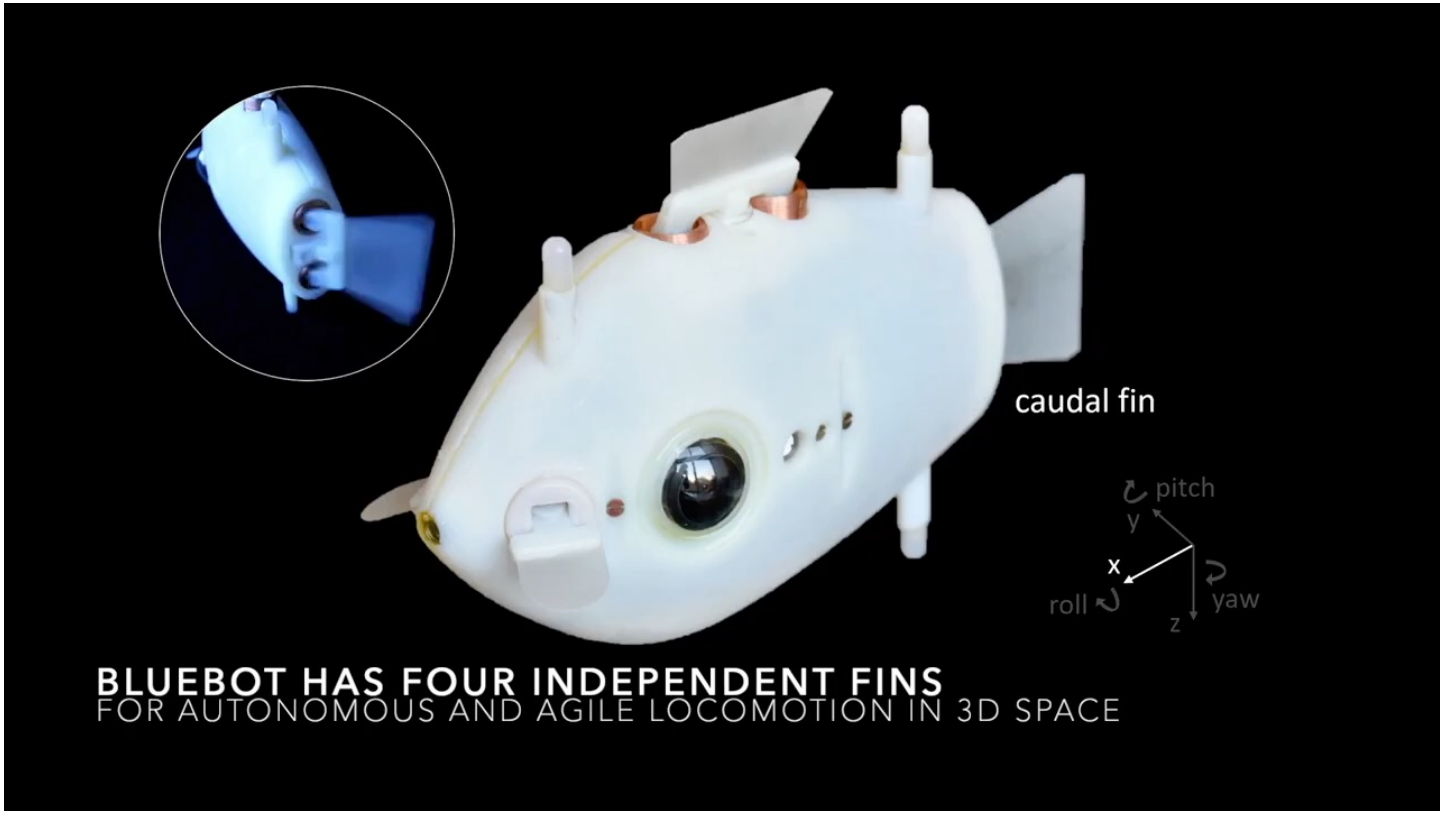


We need robots!!

Develop a platform which will enable use of implicit coordination to study multi-agent systems, swarms and emergent behaviors.

- Vision only coordination
- No inter-agent communication
- No external assistance (GPS/Mocap/Human)

Blueswarm [7]



[7] F. Berlinger, M. Gauci, R. Nagpal, Implicit coordination for 3D underwater collective behaviors in a fish-inspired robot swarm. Sci Robot. 6, eabd8668 (2021).

My Current Work

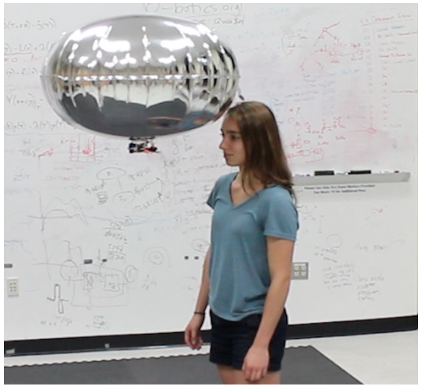
SPARX

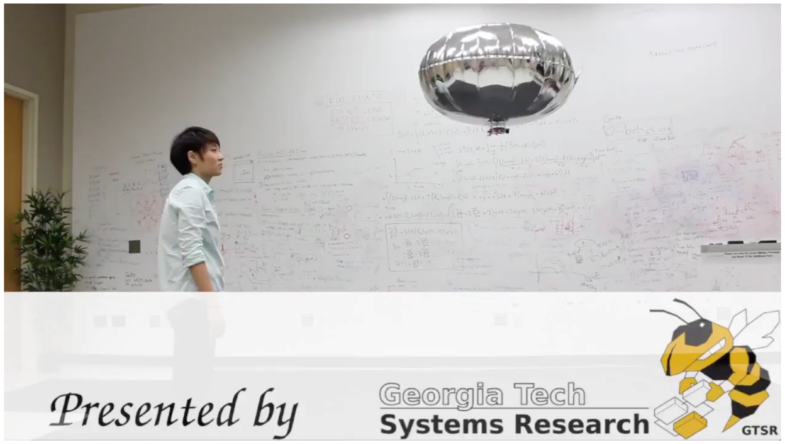
Swarming Platform for Autonomous Robots X

- Multi-agent Coordination
- Emergent Behaviors
- Swarm Manufacture and logistics

Blimp Robots

- Safer than quadcopters.
- Much longer run time
- Self-stabilizing
- less vibrations
- Can hover in air, suspended without use of any power.





[8] N. Yao, E. Anaya, Q. Tao, S. Cho, H. Zheng and F. Zhang, "Monocular vision-based human following on miniature robotic blimp," *2017 IEEE International Conference on Robotics and Automation (ICRA)*, 2017, pp. 3244-3249, doi: 10.1109/ICRA.2017.7989369.

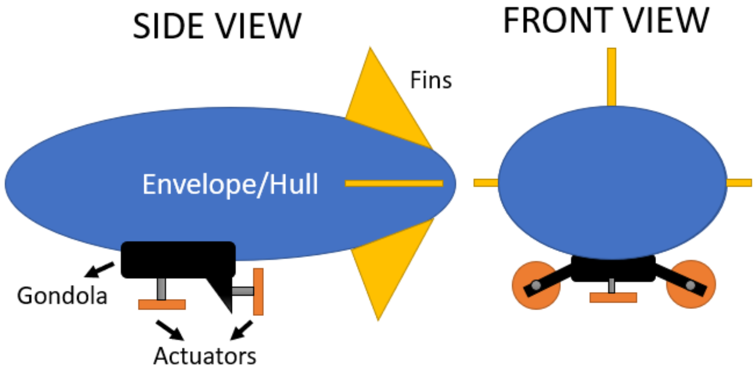
Swarming Platform for Autonomous Robots X (SPARX)

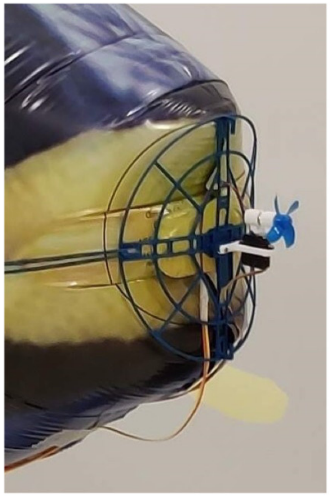
Sensing Specs

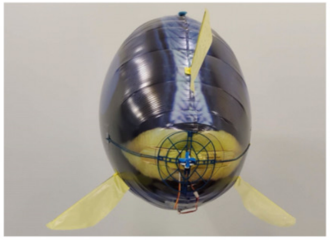
- Lidar 4m range.
- IMU
- Open MV camera 110° FOV.

MCU

- ESP 32 feather 160Mhz.

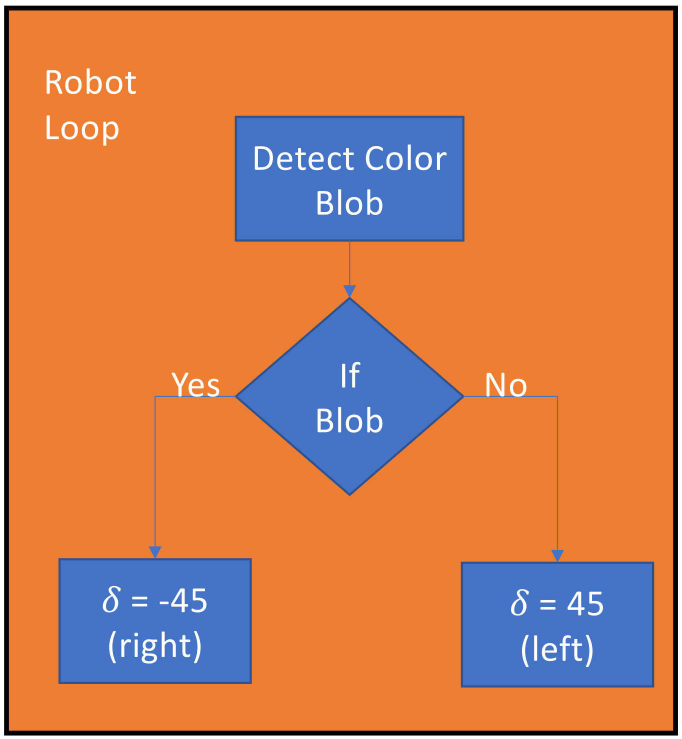






Platform Validation (Implicit Coordination)

Agent Algorithm



Inspired from blueswarm

Simulations

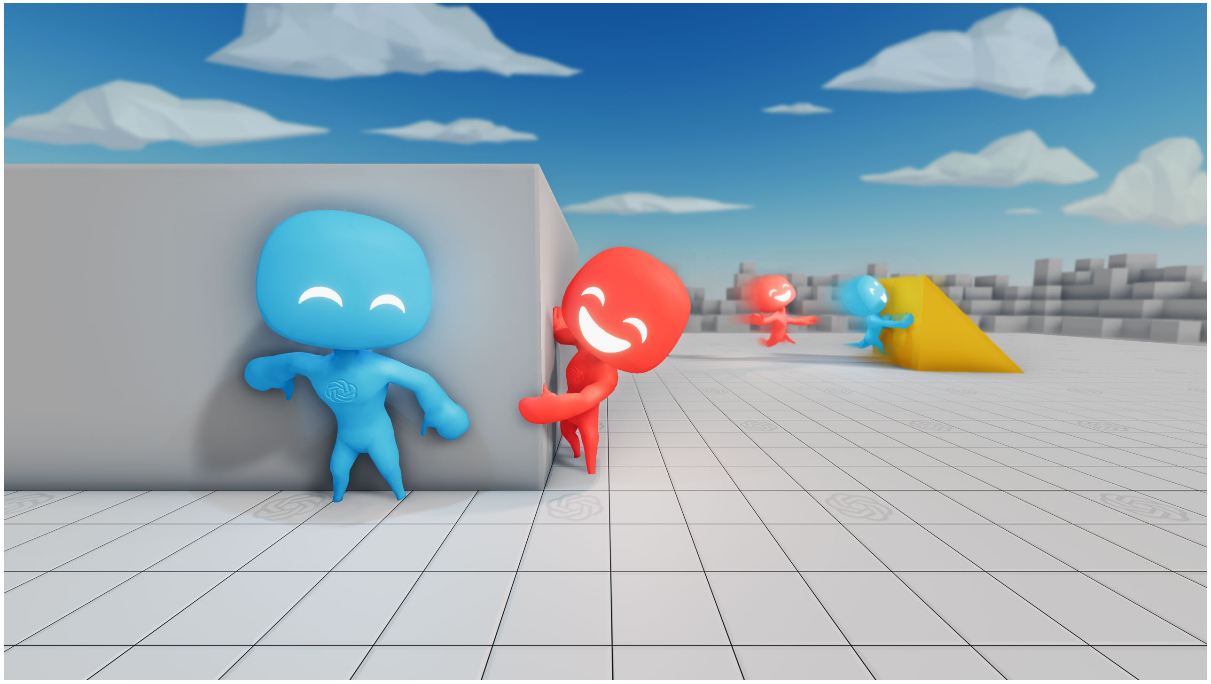
4 agents emergent milling

Real Experiments

Emergent Milling
Behavior in Air

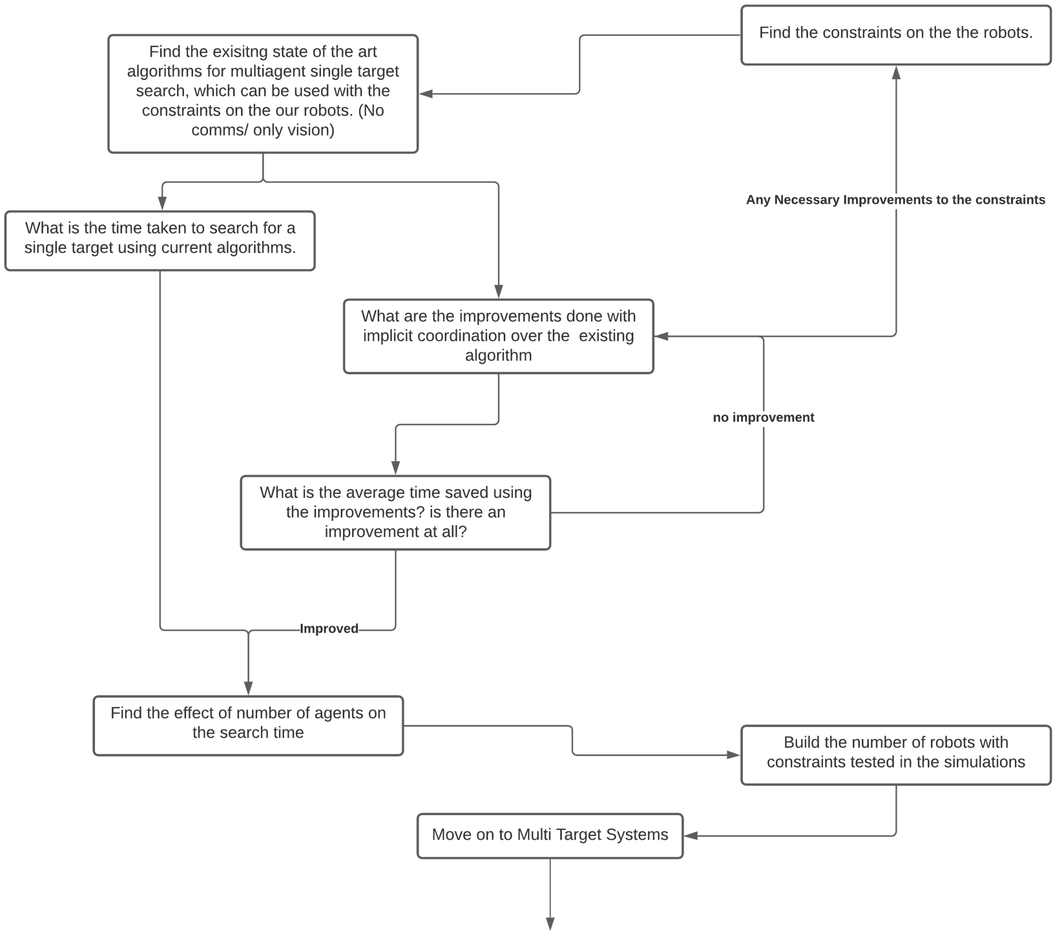
Future Work (Long-term Goal)

Multi-agent multi-target search deployable in unknown environments with no external infrastructure, no communication and human intervention.



Target Capture - 99++ Luft Balloons Competition

Research Flow Chart (Short Term)



Multi-Agent Single-Target Static Search

Objective –

- To improve the search time using implicit multiagent coordination over existing methods.

Requirements –

- To have a simple interaction rules
- Implementable and Deployable
- Better search time than random walk
- Not a success until implemented on real robots

Current Existing Search Algorithms

Citation	Method	Algorithm requirements and Assumtions	Coordination	Claims	Work Space	Meets Requirements?
[1]	Reinforced Random Walk with inhibition of return	The 2D space is divided into cells Cij. Need inter agent communication.	Local Explicit Coordination	Better Than Treditional Random Walk	2D	NO
[2]	Improved Random Walk with altered stepsize between RW inputs based on robots density.	Needs knowledge of number of neighbors and the neighbors neighbors.	Local Explicit Coordination	Decreases number of repeated searches	2D	NO
[3]	Swarm Deep Q-Learning Reinforcement Learning.	Hierarchial UAV Swarm	Explicit Coordination	Better than treditional Search algorithms	3D	NO
[4]	Fully Reactive Controller	Has omnidirectional sensing both range and contact	Implicit Coordination	Agent moves in the direction of no neighbors	2D	Partially
[5]	Isotropic Random Walk, Biased Random Walk, Correlated Random Walk	Single Agent	No Coordination	Different Random Walk	2D	Partially
[6]	Random Walk with constant step size and Random Walk with Levy Probability distrubution of the step size.	No assumptions on the robot sensing	No Coordination	Levy Flight has better search time	2D	Partially
[7]	Improved Levy Flight with Bio inspried Firefly algorithm. The Control stratergies have been examined by real world under water experiments data.	Method of repulsion needs relative distance	Implicit Coordination	Better search time than treditional Levy Flights	3D	YES
[8]	Flash Detection, Blob detection, Markov Chained model for RW.	Almost omnidirectional vision.	Implicit Coordination	Successful target capture and rendezvous	3D	YES

We compare the existing algorithms with the constraints on the platform validated
The goal is to get better results than with existing random walk algorithms

[1] Albani, Dario, Daniele Nardi, and Vito Trianni. "Field coverage and weed mapping by UAV swarms." *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. Ieee, 2017.
[2] Pang, Bao, et al. "A swarm robotic exploration strategy based on an improved random walk method." *Journal of Robotics* 2019 (2019).
[3] Mou, Zhiyu, et al. "Three-Dimensional Area Coverage with UAV Swarm based on Deep Reinforcement Learning." *ICC 2021-IEEE International Conference on Communications*. IEEE, 2021.
[4] Dhesi, Arjan, and Roderich Groß. "Area Coverage in Two-Dimensional Grid Worlds Using Computation-Free Agents." *Annual Conference Towards Autonomous Robotic Systems*. Springer, Cham, 2021.
[5] Codling, Edward A., Michael J. Plank, and Simon Benhamou. "Random walk models in biology." *Journal of the Royal society interface* 5.25 (2008): 813-834.
[6] Katada, Yoshiaki, et al. "Swarm robotic network using Lévy flight in target detection problem." *Artificial Life and Robotics* 21.3 (2016): 295-301.
[7] ASutantyo, Donny, et al. "Collective-adaptive lévy flight for underwater multi-robot exploration." *2013 IEEE International Conference on Mechatronics and Automation*. IEEE, 2013.
[8] Berlinger, Florian, Melvin Gauci, and Radhika Nagpal. "Implicit coordination for 3D underwater collective behaviors in a fish-inspired robot swarm." *Science Robotics* 6.50 (2021).

Initial Test Ideas

Implicit Coordination Based Random Walk

- Random walk[7] added with binary sensing as given in [8].
- Using dispersion in [8] to maximize area coverage.

IMU Data Integration

- Dead reckoning, trajectory mapping
- Reducing repeated searches

Expected Results

Minimum of 1.5x faster search time

Over 3x faster search time for the right number of agents.

A higher search success rate than existing algorithms

Special thanks to Ricardo Vega, Kevin Zhu, James Yang and Angel
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Questions?

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