Source Seeking with Run and Tumble Algorithm

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Research Objectives

- Develop bio-inspired run and tumble algorithm for source seeking and identification
- Extend to multiple signal types and environments
- Use low cost robotic platform and open source sensors to maximize accessibility

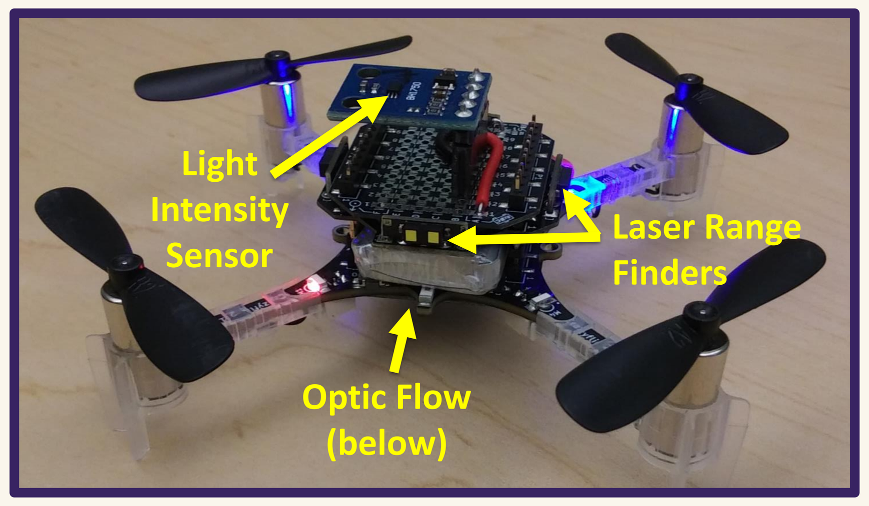
Technical Need

- People often need to find the source of a light, chemical, odor, or sound in an open environment with unmapped obstacles
- Small autonomous robots (e.g. quadcopters) paired with inexpensive sensors are a new platform for seeking and identifying sources, and development work is needed to achieve their potentially high utility
- Previous work in the field of source seeking has used computation intensive methods. One example is infotaxis (calculating probabilities that the source is in a particular direction, or probability of acquiring new information in a particular direction). [1] Another method is evolutionary robotics to find an appropriate source-seeking algorithm. [2] Machine learning can also be used to develop algorithms.
- These methods are computation intensive and/or produce a heuristic solution that is not broadly applicable to real world challenges.
- Small platforms with limited computation and power resources need a simple algorithm that is robust to a broad space of source-seeking problems.

Summary

Our research goal is to develop a robust algorithm for source seeking and identification that works for a broad category of environments and multiple signal types. To make this algorithm accessible, it should be compatible with small autonomous platforms and utilize data from inexpensive, open-source sensors. This requires low computation cost.

We propose a run and tumble algorithm inspired by bacterial chemotaxis. Our preliminary work successfully applied this method to finding a light source. We intend to extend this work to new signal types using the same process (signal and environment characterization, simulation, algorithm development, prototype, test, iterate as needed).



2. Sensor integration with Crazyflie

Figure 2. Crazyflie 2.1 quadcopter with light sensor prototype and 2 Bitcraze sensors: MultiRanger 5-axis laser range finder for object detection and the bottom-mounted Optic Flow camera with z-axis range-finder to allow autonomous flight.

Preliminary Work

1. Characterization of light signal

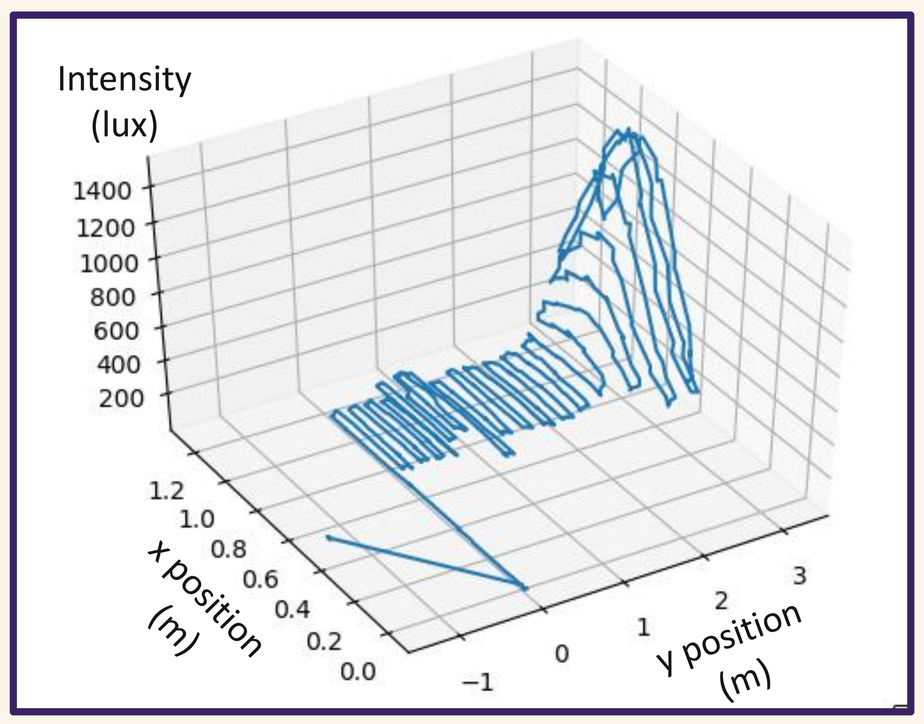


Figure 1. Light intensity is characterized by an exponential roll off on the order of L^{-2} in both the x- and y-direction.

3. Simulation of Run and Tumble with obstacle avoidance

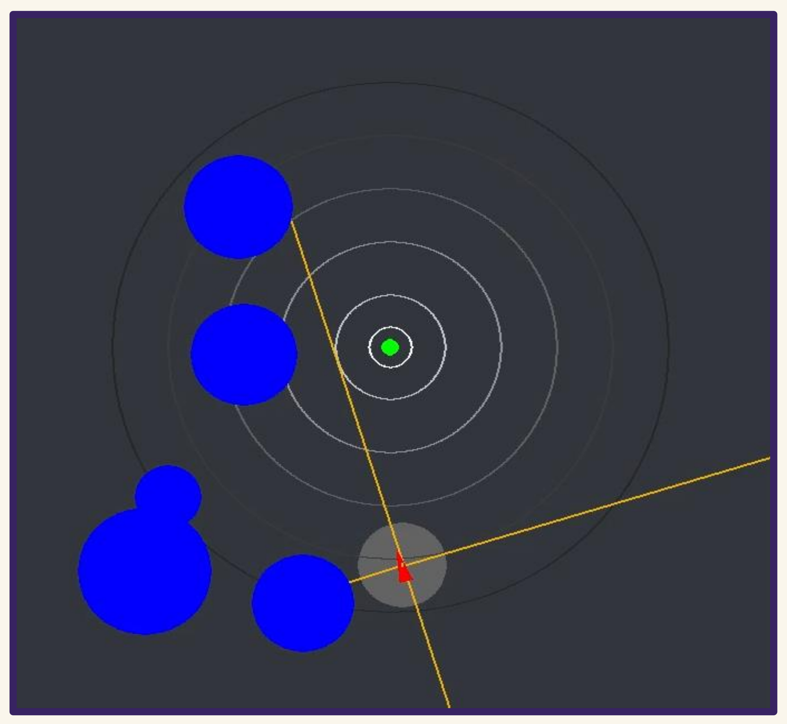
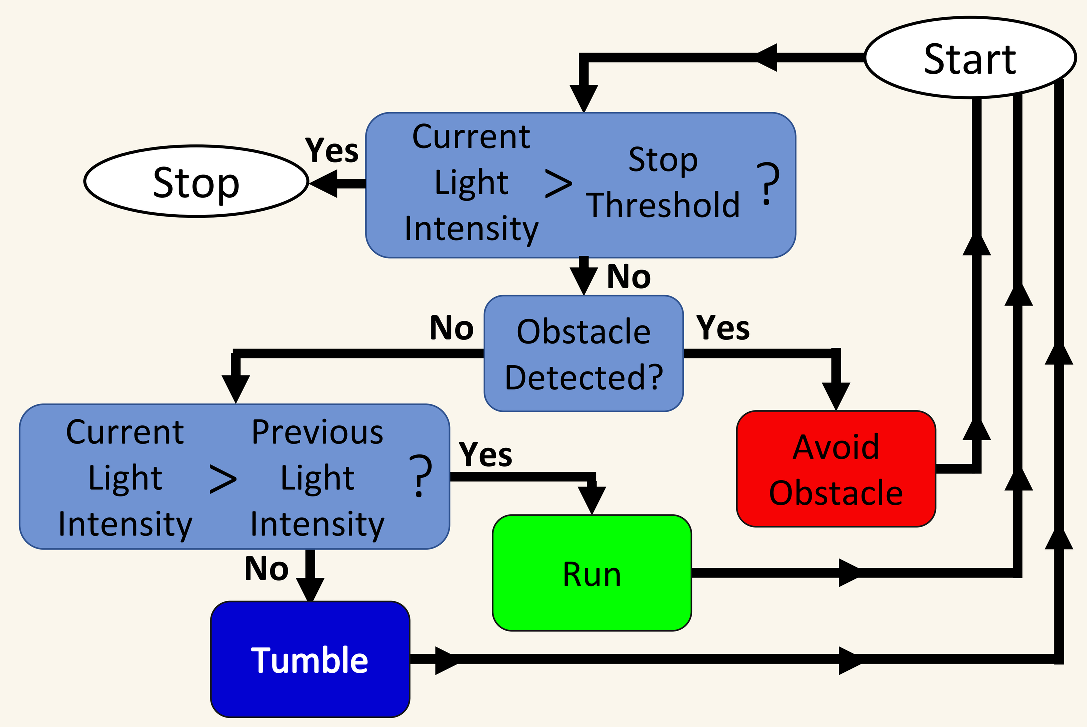


Figure 3. Simulation of Run and Tumble algorithm.

4. Design of Run & Tumble algorithm represented with Finite State Machine



Proposed Algorithm

- Run and Tumble algorithm inspired by bacterial chemotaxis
- Simple enough to be used with many signal types (not a heuristic solution)
- Obstacle avoidance will be needed to keep autonomous platform safe in unknown environments
- Developed in simulation and tested in hardware (lab, then real world)

Hardware

- Crazyflie 2.1
- Flow Deck v2 (Optic Flow) – enables autonomous flight and z-axis range
- BH1750 Light Sensor – detects light intensity up to 55k lux
- Multi-ranger Deck – laser range finding in 4 horizontal directions (front, back, left, right)

Light Seeking (Run and Tumble)

- "Run" forward at 0.1 m/s if current light intensity is greater than average of last 10 light intensity data points (5 sec), otherwise "tumble" to a random direction, start forward at 0.1 m/s
- Pre-defined max light intensity threshold triggers source identification and "stop" sequence

Obstacle Avoidance

- Pre-defined minimum obstacle distance threshold triggers "obstacle avoidance" if any multi-ranger distance is below threshold
- "Avoid Obstacle" by strafing at constant velocity away from detected obstacle for 2 seconds and then turning 20 degrees.

Preliminary Results

Initial Results:

Proof-of-concept hardware implementation demonstrated on 4 successful trial runs (0 failures).
Arena size: ~100 sq. ft.
Average search time: 1:41 sec
Number of Obstacles: 2
Number of Light Sources: 1

Limitations:

- Light source must be characterized prior to testing to determine maximum light intensity threshold
- Light source must be above the robot as light sensor faces in the positive z-direction

5. Testing with hardware in lab

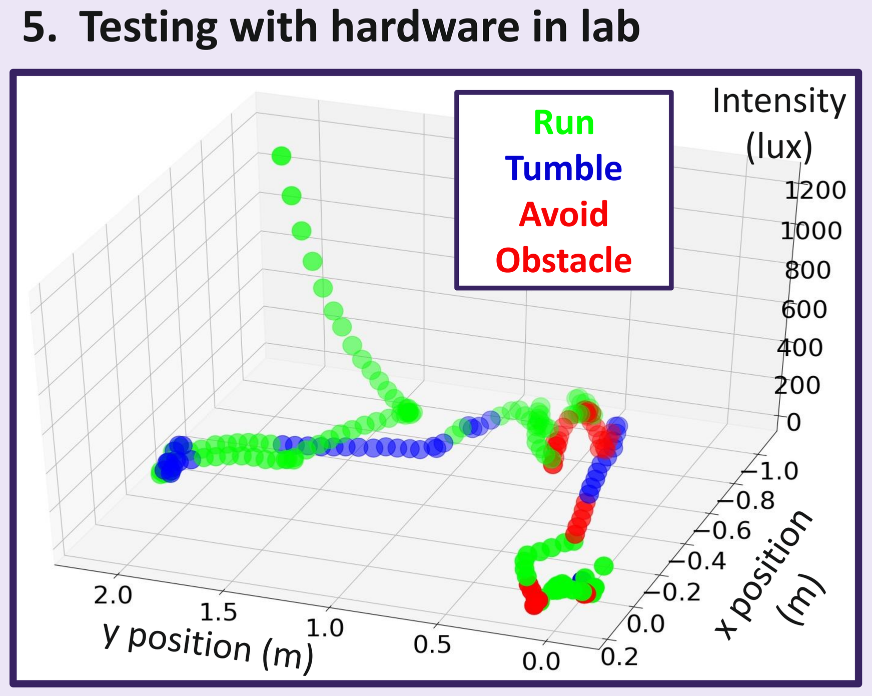


Figure 4. Hardware implementation of Run and Tumble algorithm. Marker colors indicate actions.

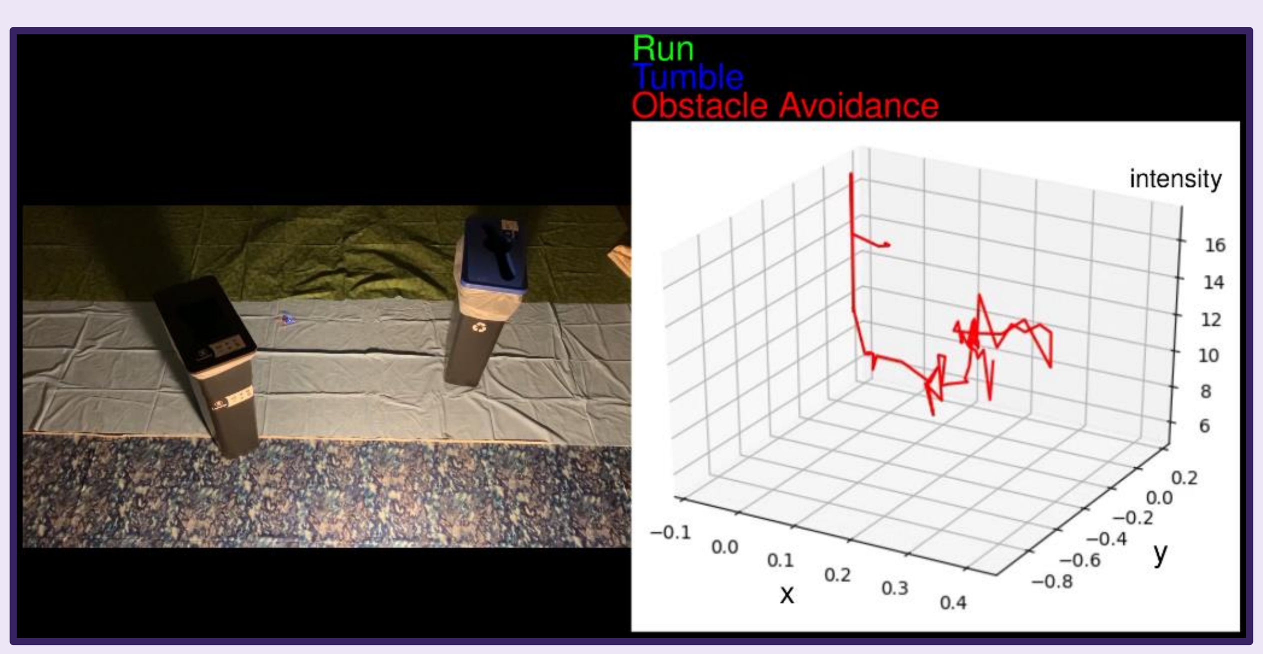


Figure 5. Footage of hardware implementation trial (left) synced with live plot of corresponding position (x-y) and intensity (z) values. The color of the line plot depends on the current behavior of the robot.

Research Plan

Algorithm development

1. Develop robust method for identification of source
2. Path optimization:
   - develop map of environment in real time to improve obstacle avoidance
   - map intensity data to optimize tumble direction

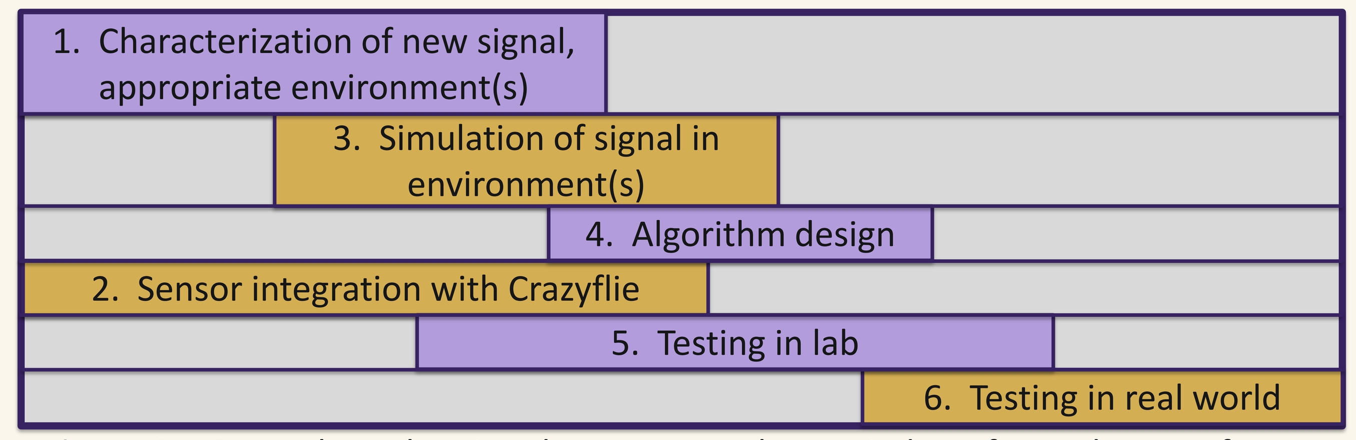


Figure 6. Gantt chart showing the process to be carried out for each type of signal. Preliminary work with the light signal carried out all steps except testing in real world.

Additional signal sensing

Extend search algorithm to work with additional signals:

1. aerosol plumes of natural gas, CO_2, etc. (chemical sensors)
2. toxic algae plumes or other water-based pollutants (chemical sensor or machine vision)
3. sound from survivors shouting, moving in damaged building (sound transducer)

Challenges:

Light provides a steady gradient with L^{-2} dependence but alternate signals have:

- poorly defined gradients
- significant decay due to dispersal, turbulence
- noise from reflections

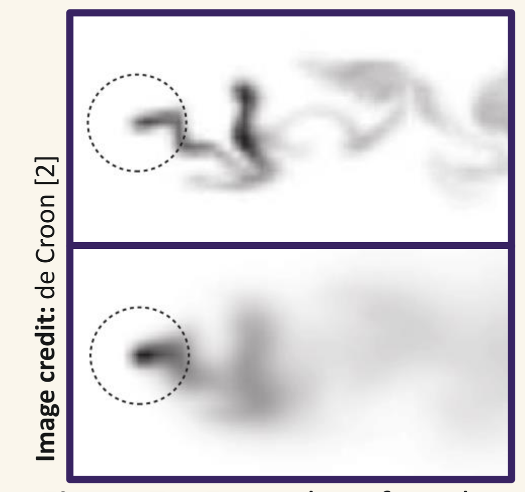


Figure 7. Examples of methane plumes in high turbulence (*top*) and low turbulence (*bottom*).

Figure 8. Example of algae bloom and effluent (pollution source) in Grays Harbor, WA as seen by aerial photography.

Swarm integration

An advantage of using low-cost quadcopters is the ability to put several in the field at one time. This can improve source location through:

- Shared information
- Triangulation of sound
- Identification of bounding edges of plumes by simultaneous sensing of a large area

Expected Results

Improved run and tumble algorithm and autonomous source identification:

- Shared information between agents to estimate a signal gradient
- Non-random tumble direction based on signals from multiple agents

Improved object detection and avoidance:

- Creation of a map based on obstacle detection from all agents
- Efficient path planning based on knowledge of sensed obstacles and signal gradient calculated from all agents

References

[1] M. Vergassola et al, "'Infotaxis' as a strategy for searching without gradients," Nature, vol. 445, no. 7126, pp. 406–409, Jan. 2007.
[2] G.C.H.E. de Croon et al, "Evolutionary robotics approach to odor source localization," Neurocomputing, vol. 121, pp 481-497, Dec 2013.
[3] Washington State Department of Ecology. 2020. Eyes Over Puget Sound: 2019 in Review, Report, January 10, 2020. Ecology Publication No. 20-03-070.

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