Search for a Rendezvous with Lost Target at Sea

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1. Introduction

- **Goal**: Given the search parameters select the best search pattern to find a passive floating target at sea.
- **Example Scenarios**:
  - Search and rescue operations for survivors of a sinking ship.
  - Environmental monitoring with short-range communication devices.
  - Search for floating debris (e.g. black boxes).
- We propose spiral patterns (Fig. 1) as our search strategy, since they are known to be the **natural search strategies** used by animals and humans [1] and they are also empirically proven to be the **emergent behavior** of a search vehicle with **optimal control** [2].

Fig.1: Simulated spiral search pattern on Microsoft Bing Maps©. The red dots indicate the waypoints of a searcher robot and the yellow dots represent the target waypoints.

2. Guaranteed Search Analysis

- Given a two-dimensional search region with radius r, a searcher robot with maximum speed s_r and communication radius b, we would like to find a passive target which is known to be drifting in the search region with an estimated maximum speed s_d.
- We analyze two circular patterns which are the worst-case search time approximations of **inward** and **outward** spiral patterns.
- The total number of circular rounds that the robot needs to complete for clearing the entire search region is given by

$$n_s = \left\lceil \frac{r}{b} \right\rceil \tag{1}$$

- The time taken to clear one circular round with radius r, is

$$\tau = \frac{2\pi r}{s_r} \tag{2}$$

- The total time taken by the robot to search the complete region is,

$$\tau_{tot} \leq n_s \tau \tag{3}$$

Inward spiral approximation

- If the robot performs a circular search pattern with diminishing radius b for each circular round then, the total or maximum capture time, given the drifter is within the search region, is calculated as,

$$\tau_{tot} = \frac{2\pi n_s}{s_r} \sum_{i=0}^{(n_s-2)} (r - ib) \tag{4}$$

- And, the minimum capture time is,

$$\tau_{min} = \frac{4\pi b n_s}{s_r} \tag{5}$$

Outward spiral approximation

- If the robot performs a circular search pattern with increasing radius b for each circular round then, the total or maximum time for a guaranteed capture is,

$$\tau_{tot} = \frac{2\pi n_s}{s_r} \sum_{i=0}^{(n_s-2)} ib \tag{6}$$

only if the the speed of the robot s_r satisfies the condition in Eq. 7, with respect to the speed of the drifting target s_d.

$$s_r > \frac{2\pi r s_d}{b} \tag{7}$$

3. Controlled Simulations

- We validated our analytical results on our interactive web-simulator (Fig.1).
- The **mean-time-to-find** the target was calculated as a function of the target's **initial location distribution** and the **communication radius** of the searcher.
- We considered three distributions: ***uniform***, ***triangle*** and $|x|$ while varying the communication radius (with respect to the search radius $\approx$ 700m) for 1000 trials. The results are presented below:

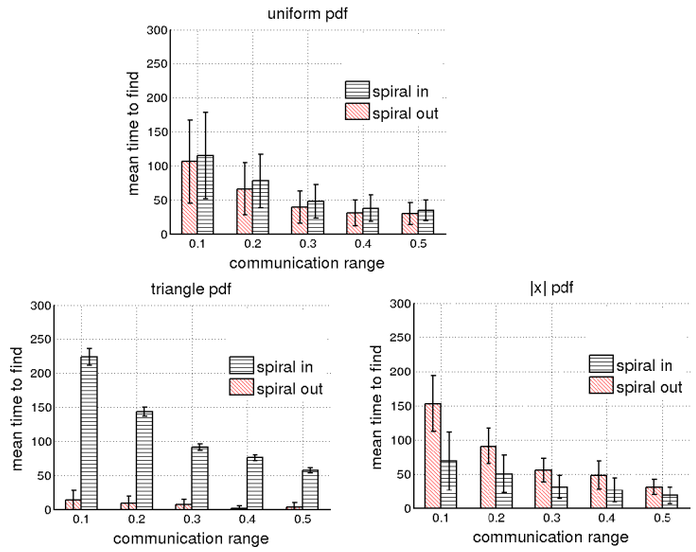

Fig. 2: Mean-time-to-find the target as function of initial location distribution and communication radius.

- The maximum speed of the robot and the target were considered as 1.2 m/s and 0.5 m/s respectively, based on our field experiments for all the simulation results.
- The results in Fig. 2, confirm our hypothesis that mean-time-to-find the target is shorter for':
  - outward spiral with triangle distribution (initial locations are concentrated at the mean of the search region) and
  - inward spiral with $|x|$ distribution (initial locations are concentrated at the circumference of the search region).

4. Field Experiments

- As a proof of concept for our simulated results, we performed real experiments in the Caribbean Sea (Fig.3, bottom).
- The searcher robot was an Autonomous Surface Vehicle, Kingfisher from Clearpath Robotics and the floating target was an in-house hardware setup with an Android MiniPC and a GPS (Fig. 3, top).

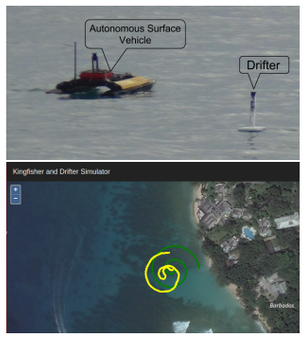

Fig.3: System setup(top) and the search region(bottom) with Kingfisher's path as yellow color and simulated path as green color.

5. Conclusion and Future Work

- **Conclusion:**
  - We provided analytical results for guaranteed capture time for inward and outward search patterns.
  - We presented simulation results which confirm our hypothesis.
  - We discussed field experiments as a proof of concept of our analytical results.
- **Future Work:**
  - Large-scale field trials will be performed to support our preliminary results.
  - Track and search for multiple targets is a natural follow-up to this work.

6. References

- **E. Gelenbe et al.** "Autonomous search by robots and animals: A survey", Robotics and Autonomous Systems, 1997.
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