Passive Localisation with Geometric Objectives

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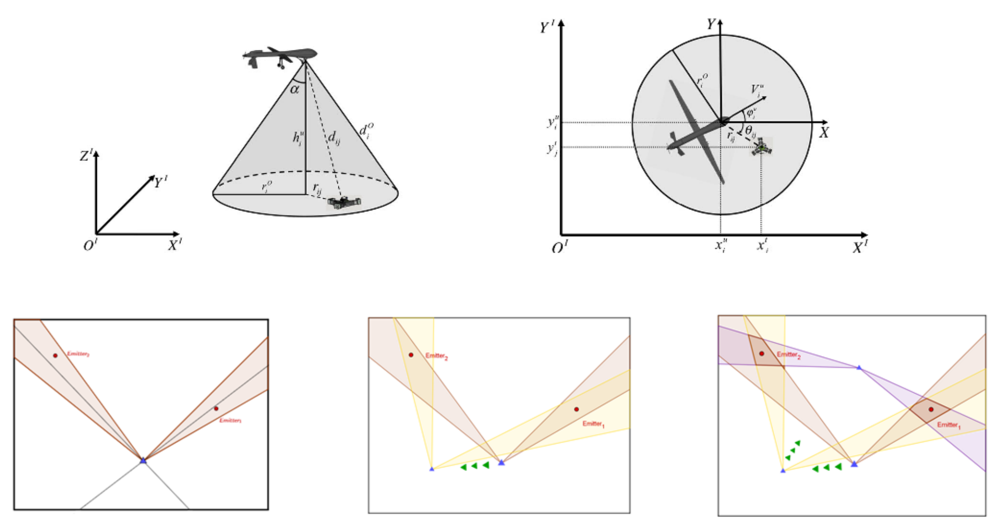
Measurements from Passive Sensors

Passive Sensors cannot actively scan but they pick up transmissions, and they provide **the angle of the source's direction**. Examples of **passive sensors** are microphones, light detectors, heat detectors, RF frequency detectors, etc.

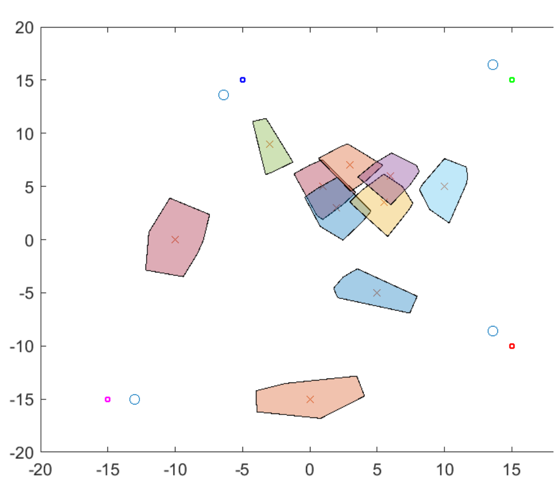


Introduction

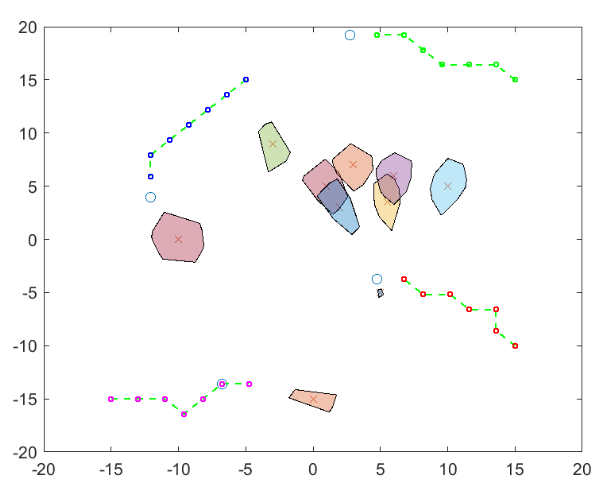
There has been a development of applications with autonomous vehicles that utilise passive sensors in the recent years. In a given area, there are static emitters, and movable passive sensors, which means that the sensors can move, but they are unable to actively scan the area. When the emitters send a transmission, the sensors get an estimation of the emitters' angular position relative to theirs. Due to environmental interference, the sensors get an angle of possible directions from the signal's point of origin, and because they have limited range, a cone is created that contains the position of the transmissions source (or sources). **Our objectives is to localise the position of *k* static emitters in an area with *m* mobile sensors .**

A Geometric Approach to Passive Localisation

The framework replaces the statistical analysis of sensor management by over-approximating geometric objectives. We analyse the emergent behaviour and show robustness of the proposed algorithms. A simulation of our centralised algorithm with 4 sensors is shown below.



Step 2



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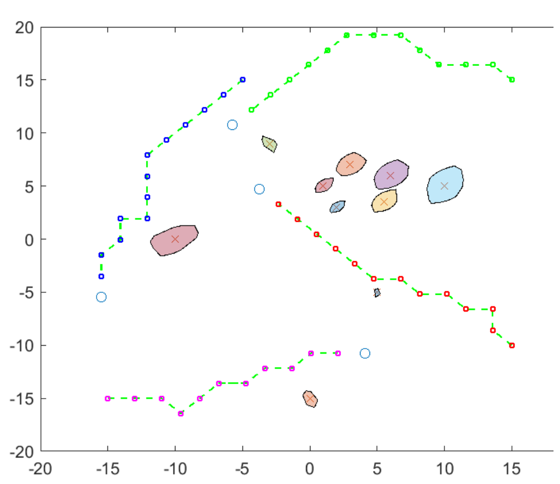

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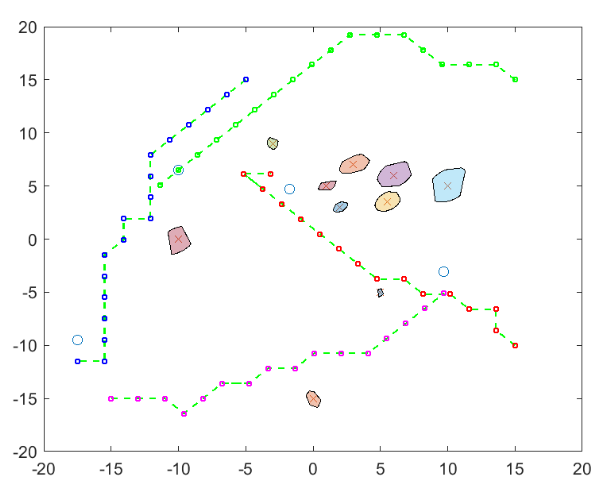

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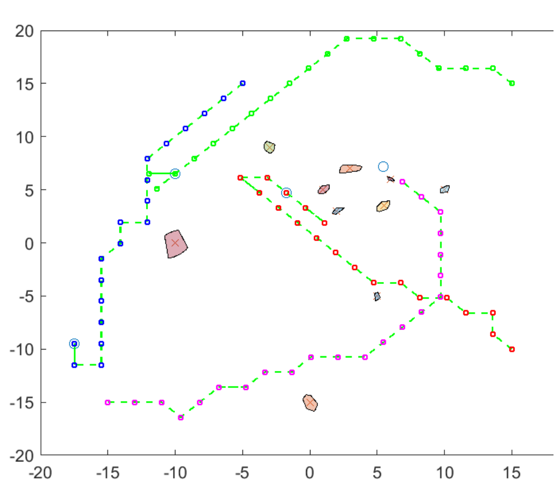

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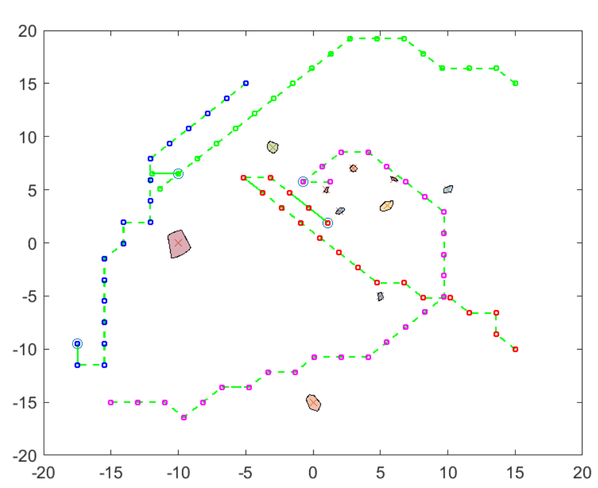
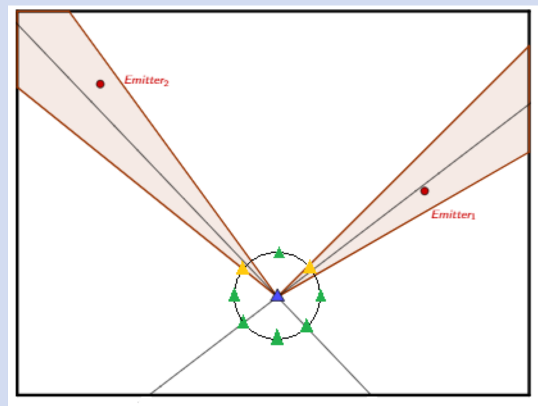


Step 30

Summary

- Geometric approach provides reliable polygonal bounds on the location of an emitter by only considering the geometry of the problem without using a prior distribution - thereby reducing the reliance on initial assumptions and initial data.
- We develop an approach that is based purely on the geometry of the search task; an approach that can complement more sophisticated methods based on Bayesian inference by bounding regions being considered for further processing

Decision Making - Selecting Direction



Discrete Set of Directions

- The localization process is iterative. A sensor is detecting the presence of an emitter within an area, and calculating the intersection of the measurement with the polygon that bounds currently the emitter's location.
- The decision-making process estimates neighbourhood positions in respect to a potential area reduction.

Our Benchmark is a Greedy Algorithm

As a benchmark we have a greedy algorithm that chooses the next position by evaluating an objective function. Examples of such functions are: Given the current position x_t, and the observed area P_t, minimise the total area of the maximum intersections A_i, $i \in \{1, \dots, \ell(t)\}$, of the observed area and the triangle of the sector's field of view

$$f_1(P, x) = \min_{d \in \mathcal{D}} \left(\max_{\theta_i \in [0, 2\pi]} \sum_{i=1}^{\ell(t)} A_i(\theta_i, x + d) \right) \tag{1}$$

Function $A_i(\theta, x)$ represents the area of intersection between the polygon P_{ti} with the sensor's field of view which is centered at position x and has direction θ. Another one is the following: Given the current position x_t, and the observed area P_t, minimise the largest observed polygon P_{tj}, $i \in \{1, \dots, \ell(t)\}$

$$f_2(P, x) = \min_{d \in \mathcal{D}} \left(\max_{i \in \{1, \dots, \ell(t)\}} \left(\max_{\theta_i \in [0, 2\pi]} A_i(\theta_i, x + d) \right) \right) \tag{2}$$

Evaluating the Objective Functions According to Global Objectives

- Minimise the area observed when the maximum time step t_{max} is reached

(a) Minimise the total area

$$\min_{x_{1:t_{max}}} Area\left(P(x_{x_{1:t_{max}}})\right)$$

(b) Minimise the area of the maximum polygon observed

$$\min_{x_{1:t_{max}}} Area\left(\max_i P_i\left(x_{x_{1:t_{max}}}\right)\right)$$

For the second stopping condition taken into consideration, the same can be applied when the set of trajectories Tr is defined. For example, an objective is to get the average area of the polygons to be less than a given value tol. Let Tr be the set of the trajectories which achieve in the end the average observed area to be less than tol that is

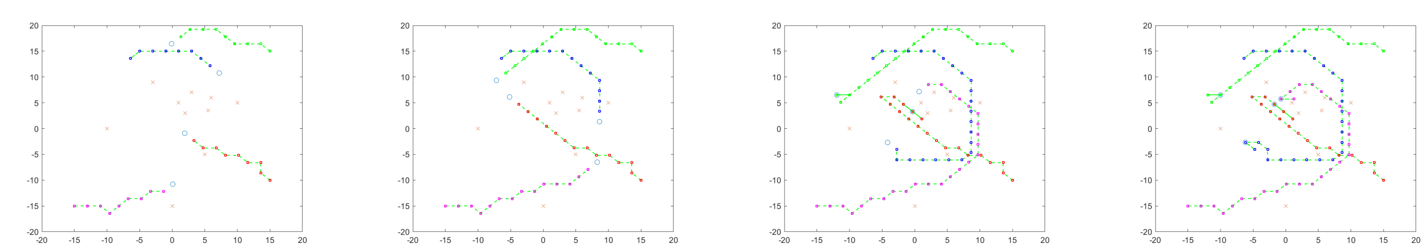
$$Tr = \left\{ x : \mathbb{N} \to \mathbb{R}^2 \mid \exists\, T \text{ s.t.} \operatorname*{avg}_i \left(Area(P_i(x_{1:T})) < tol\right) \right\} \tag{3}$$

- Find the $x^*_{1:t_0}$ that the minimum length, that is

$$x^*_{1:t_0} = \operatorname*{argmin}_{x_{1:t} \in Tr} \left\{ t \in \mathbb{N} : \operatorname*{avg}_i \left(Area(P_i(x_{1:t})) < tol\right) \right\} \tag{4}$$

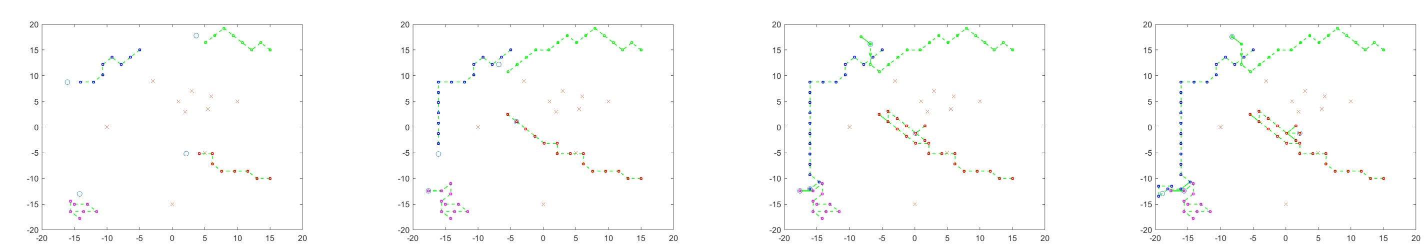
Emergent Behaviours

The sensors act independently without sharing information. It becomes apparent that the sensors in figure 1 gravitate towards the centre of the area, where a cluster of emitters lies, which appears to be the emergent behaviour of the greedy algorithm with objective function (1). But in Figure 2 the sensors' movement seems random, and it depends on the sensors' starting positions.



Step 9 Step 14 Step 25 Step 30

Figure 1. The run of the **greedy Algorithm with the objective function (1)**. There are four sensors, each one acting independently, and they are gravitated towards the cluster of the emitters in middle of the area.



Step 8 Step 15 Step 23 Step 30

Figure 2. The run of the **greedy Algorithm with the objective function (2)**. There are four sensors, each one acting independently, and they appear to have a random movement.

References

[1] Fredrik Gustafsson. *Statistical sensor fusion*. 1 edition, 2010.

[2] Simo Särkkä. *Bayesian Filtering and Smoothing*. IMS Textbooks. Cambridge University Press, 2013.

[3] Theofilos Triommatis, Igor Potapov, Gareth Rees, and Jason F. Ralph. A geometric approach to passive localisation. In *2022 25th International Conference on Information Fusion (FUSION)*, pages 1–8, 2022.

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