Area Inspection by Robot Swarms through Exploitation of Information Gain

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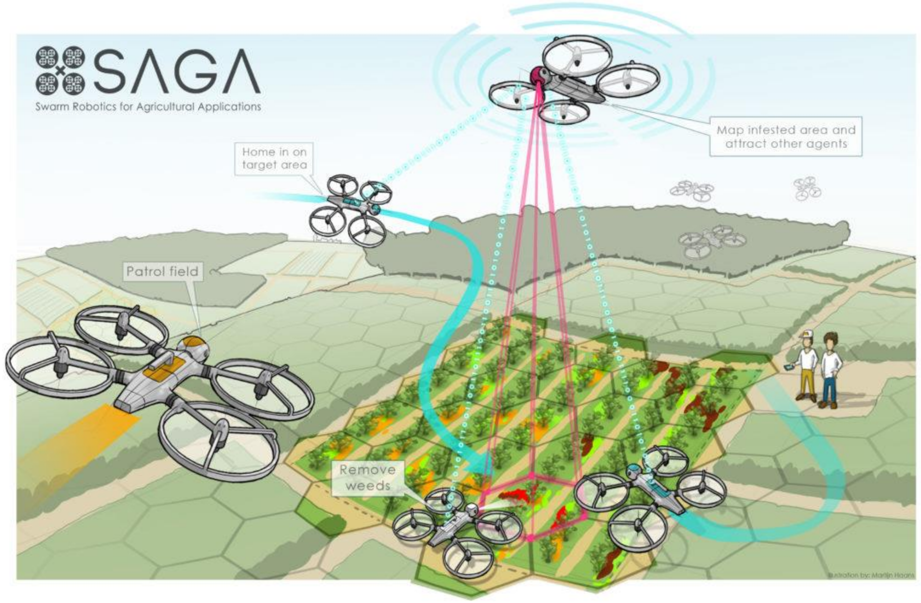
My main research interests span over swarm robotics, self-organizing systems as well as multi-robot systems.

Study Case

Precision Agriculture:

- An application domain presenting expansive fields and needs for collaboration
- Robotics technologies promise a remarkable impact
- Far from exploiting the full potential of autonomous robots and multi-robot collaboration



The approach can fit other study cases as:

- Search and rescue
- Monitoring and mapping applications

In a Nutshell

- A decentralized approach for area coverage and mapping
- Grid world assumption
- Probabilistic area selection based on information entropy and information gain
- Direct consideration of neighboring agents through broadcast communication
- Relies only on local knowledge
- No free parameters and no pre-operational tuning needed

Information Gain ...

In its simplest form the information gain writes:

$$IG_n(c) = \underbrace{H_n(c)} - \underbrace{H_n(c|o_c(n))}$$

Difference between:

- the residual uncertainty that a robot has about a cell
- the conditional entropy given a robot observation

... and Entropy

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$$H_n(c) = -\sum p_n(c) log(p_n(c))$$

the entropy computed over the current knowledge of the robots about the cell

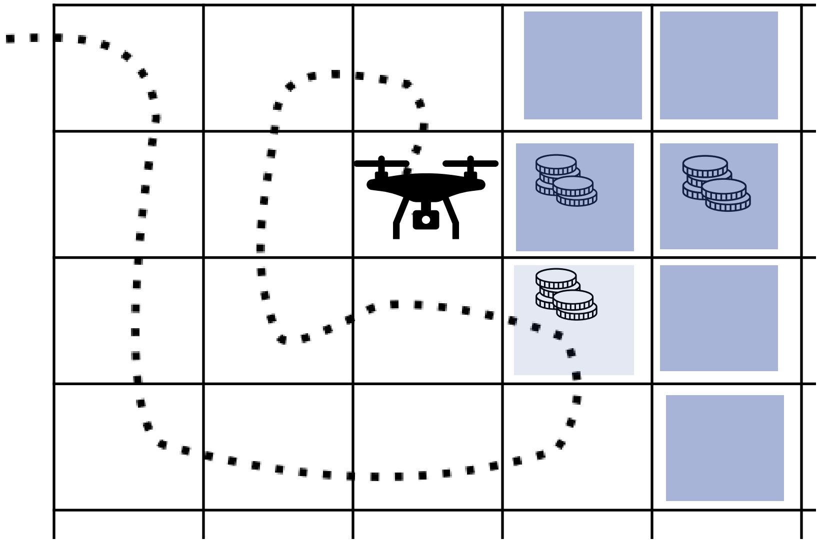
$$H_n(c_{i,j}|\tilde{o}_{i,j}) = -\sum_{o} p_n(\tilde{o}_c) \sum_{c} [p_n(c|\tilde{o}_c) \log (p_n(c_c|\tilde{o}_c))]$$

the conditional entropy expressed according to the robot observation

Information Theory Enriched Random Walk - 1

We use the IG to assign probabilities to the cells:

- Undiscovered regions have a greater associated IG
- Already discovered regions with unmapped POIs have a greater associated IG



Information Theory Enriched Random Walk - 1

We use the IG to assign probabilities to the cells:

- Undiscovered regions have a greater associated IG
- Already discovered regions with unmapped POIs have a greater associated IG

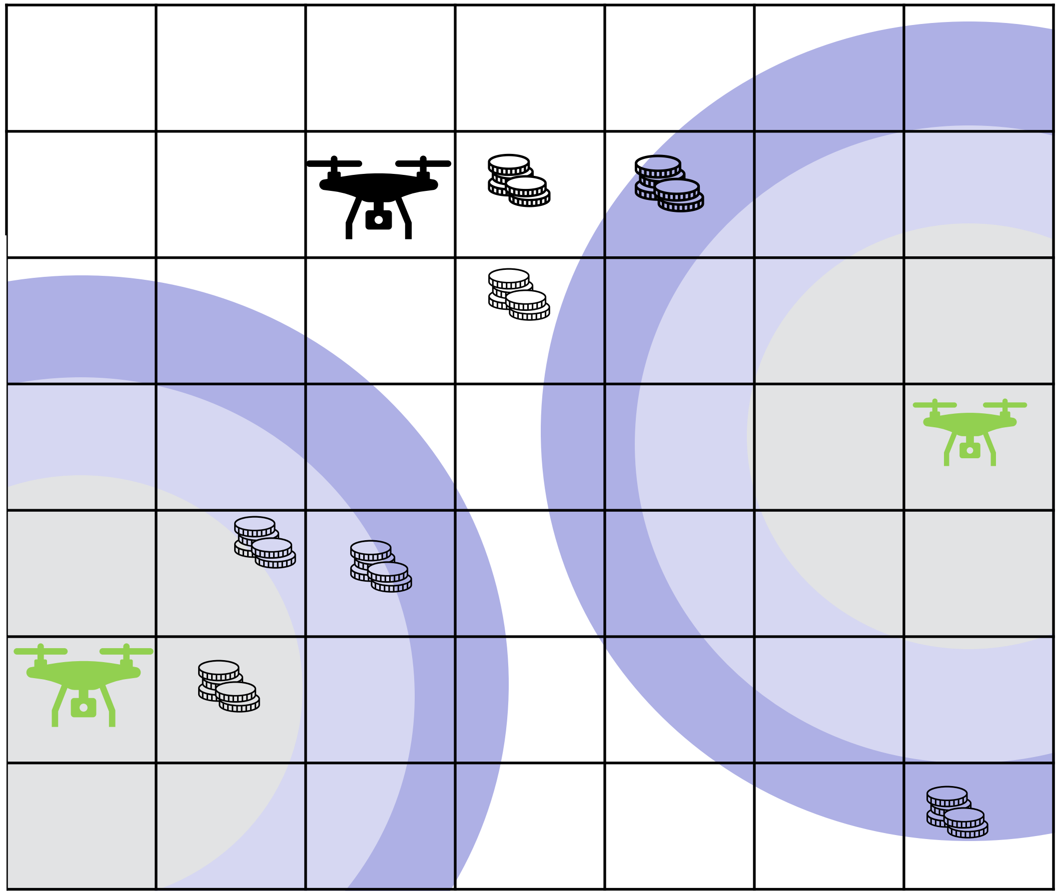
That is:

$$P_n(c) = \frac{IG_n(c)}{\sum_{\tilde{c} \in C} IG_n(\tilde{c})}$$

Information Theory Enriched Random Walk - 2

… … … …

- Regions closer to other robots have a smaller associated IG



Information Theory Enriched Random Walk - 2

… … … ...

- Regions closer to other robots have a smaller associated IG

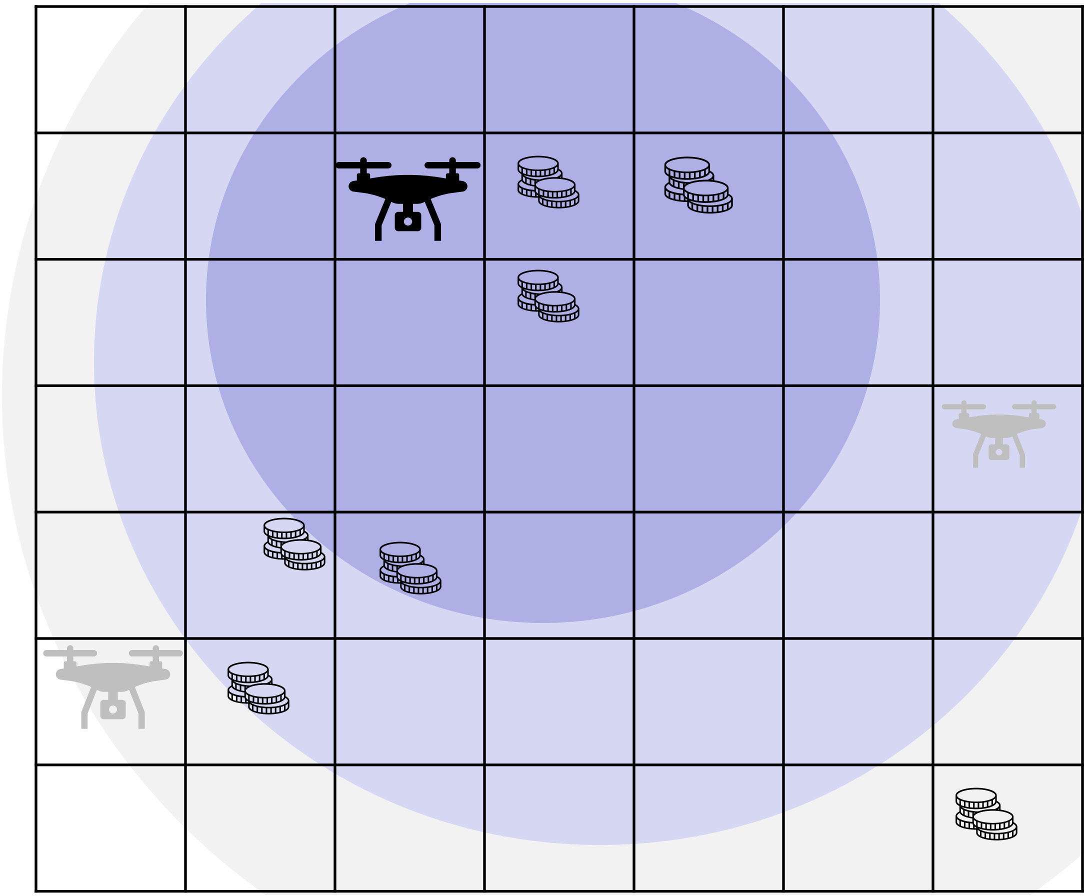
That is:

$$P_n(c_{i,j}) = \frac{IG_n(c)}{\sum_{\tilde{c}\in C} IG_n(\tilde{c})} \prod_{\tilde{n}\neq n} [1 - \frac{IG_{\tilde{n}(c)}}{\sum_{\tilde{c}\in C} IG_{\tilde{n}}(\tilde{c})}]$$

Information Theory Enriched Random Walk - 2

… … … ...

- Regions too far from the robot have a smaller associated IG



Information Theory Enriched Random Walk - 2

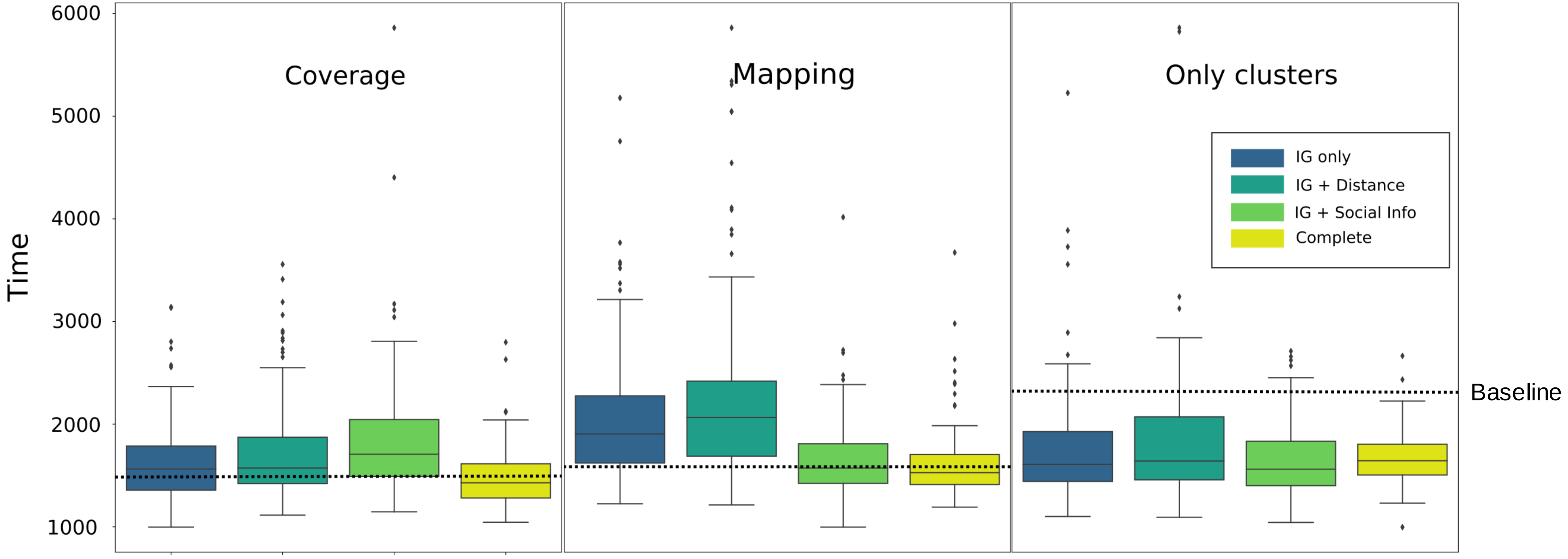
… … ...

- Regions too far from the robot have a smaller associated IG

That is:

$$P_n(c) = \frac{d_n(c)^{-1} IG_n(c)}{\sum_{\tilde{c}\in C} d_n(\tilde{c})^{-1} IG_n(\tilde{c})} \prod_{\tilde{n}\neq n} \left[1 - \frac{d_{\tilde{n}}(c)^{-1} IG_{\tilde{n}}(c)}{\sum_{\tilde{c}\in C} d_{\tilde{n}}(\tilde{c})^{-1} IG_{\tilde{n}}(\tilde{c})} \right]$$

Preliminary Results



Results compared against the RRW presented in Field coverage and weed mapping by UAV swarms
D Albani, D Nardi, V Trianni - 2017 IEEE/RSJ IROS

Pros and Cons

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No Parameters

PRO

- No free parameters to be set
- No pre-operational tuning needed
- Allows or fast deployment

Swarm Properties

PRO

- Completely Decentralized
- Robust to failures
- Scalable
- Relies on local knowledge

Probabilistic Selection

CON

- Might lead to wrong decisions
- Wrong decisions increase operational time

Communication and Performances

CON

- Performances should be improved
- Lack of specific information sharing protocols
- Is it really scalable?

Future Work

Being this a preliminary work there is room for improvement

- Belief propagation (via Gaussian Processes) to:
  - Decrease the communication overhead
  - Decrease the computational load
  - Increase the scalability
- Introduction of more accurate sensor models for perception
- Real world testing

Area Inspection by Robot Swarms through Exploitation of Information Gain

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- A decentralized approach for area coverage and mapping
- Probabilistic area selection based on information entropy and information gain
- Relies only on local knowledge
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