Occupancy Based Map Searches Using Heterogeneous Teams

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This work considers the problem of searching a two dimensional space for targets using a team of heterogeneous agents. The system maintains a world model which includes the estimate of possible target states. The issue of compelling agents to converge on possibly moving targets and continuing to search new regions is formulated as a model predictive control problem. The world model is propagated forward in time and control decisions are made on the predicted future state of the world. Agents formulate control decisions for a fixed number of time steps by optimizing a team based objective function which allows for control and timing constraints.

Nomenclature

\[ \alpha \] Heading penalty coefficient

\[ \superscript{k} \] Agent (UAV) number index

I. Introduction

Past work in optimizing searches. Durrant-Whyte et. al. Anawat’s work.

II. Predictive World Model

We can maintain a current estimate of the world using the inputs from each agent at each time step \( k \). In addition, in order to form this as a model predictive control problem, the world estimate can be propagated forward in time by \( d \) time steps. The world estimator can be shown below in Figure 1.

![Figure 1. Predictive World Model using inputs from n agents.](image)

There are several situations where this type of predictive world model becomes useful. One example is in the situation of a moving target. Without the predictive world model, the agent will simply try to “catch”
the target by trying to converge on its present location without knowledge of where it is going. This leads to slower convergence. However, with the predictive world estimate, it would be possible to converge on where the target is going to be in the future. This idea is illustrated below in Figure 2.

Figure 2. Agent converging to target with and without predictive world estimate.

In this situation, the curved trajectory represents what might happen if the agent did not have the capability to predict where the target would be at time k+d. It would simply try to do what was best for itself only 1 step ahead. However, the straight line represents what might occur if the optimization routine was able to access the predictive world model. The agent would then be planning trajectories which would benefit it in d steps in the future rather than just focusing on the immediate future.

Another situation where this might benefit the agent is if the target is hidden behind a “wall” of low scores as shown below in Figure 3.

Figure 3. Target hidden behind wall of low scores.

In this situation, with the ability to look ahead more than 1 step, the agent would choose a long and indirect trajectory to the target. But with the predictive world model, it would be possible for the agent to plan d steps ahead and then swiftly converge to the target.

III. Feasible Set

Different agents might have different capabilities and therefore be able to reach different regions in a given look ahead window based on their saturation limits, max airspeed, etc. This is shown below in Figure 4.
The team based objective function is then formulated as a function of the maximum possible score in each agent’s feasible set.

The objective function can then be optimized individually for each agent. Cooperation between the agents is indirectly achieved due to the fact that they all reference the same predicted world model and same occupancy based map. This becomes a sort of patrol regions for each agent based on its individual capabilities. These patrol regions could still overlap and would dictate which possible trajectories are feasible at each generation of the evolutionary computation process. The look-ahead horizon could be extended as far as would be computationally efficient given the number of agents and the complexity of the team based utility function. This idea is illustrated below in Figure 5.

![Figure 5. Multi agent team with individual patrol areas.](image)

### IV. Problem Formulation and Optimization

The problem can now be formulated as an optimization problem over the feasible set described previously. The

1. Obtain agent’s state.
2. Calculate feasible (reachable) set of cells.
3. Propagate world estimate forward in time by d steps.

4. Optimize objective function over set of reachable cells to obtain set of controls which have terminal state at optimal location and satisfies timings and/or control constraints.

Note that when we propagate the world estimate, we only change the world estimate to account for possible target velocity and the possibility that the cell scores could be time varying (to model the fact that the target location estimate becomes more uncertain as time progresses).

V. Comparison and Simulation

Simulation using a greedy algorithm (d=1) and a planar kinematic plant model where the agents only look 1 step ahead is shown below in Figure 6. This can be later compared using the optimizing algorithm with the predictive world model.

![Figure 6. Occupancy based map search with three agents.](image)

VI. Conclusion and Further Research

Conclusion goes here.
VII. Acknowledgements

Acknowledgements goes here.