Collective Anomaly Perception During Multi-Robot Patrol: Constrained Interactions Can Promote Accurate Consensus

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Introduction

An important real-world application of multi-robot systems is multi-robot patrolling (MRP), where robots must carry out the activity of going through an area at regular intervals. While MRP algorithms show some maturity in development, a key potential advantage has been unexamined: the ability to exploit collective perception of detected anomalies to prioritize security checks. Here, we examine the performance of unmodified patrolling algorithms listed in Table 1, when they are given the additional objective of reaching an environmental perception consensus via local pairwise communication and a quorum threshold.

Figure 1: Trajectory plot of a system of eight robots executing the SEBS patrol algorithm for over an hour, with each unique color representing a single robot and its patrol route.

Experimental Methodology

Simulation results are generated using a simulation package that models agents as a differential drive robot [1]. Robots are capable of local communication between one another within a communication radius, as shown in a simulation snapshot in Figure 2. Upon visiting a node during a patrol, agents measure the node for an anomaly, and build a representation of the world according to the measurements they make, as well as measurements shared with them via pairwise communication. Agents navigate a graph map as seen in Figure 4 and decide on nodes to visit based on the patrolling algorithm.

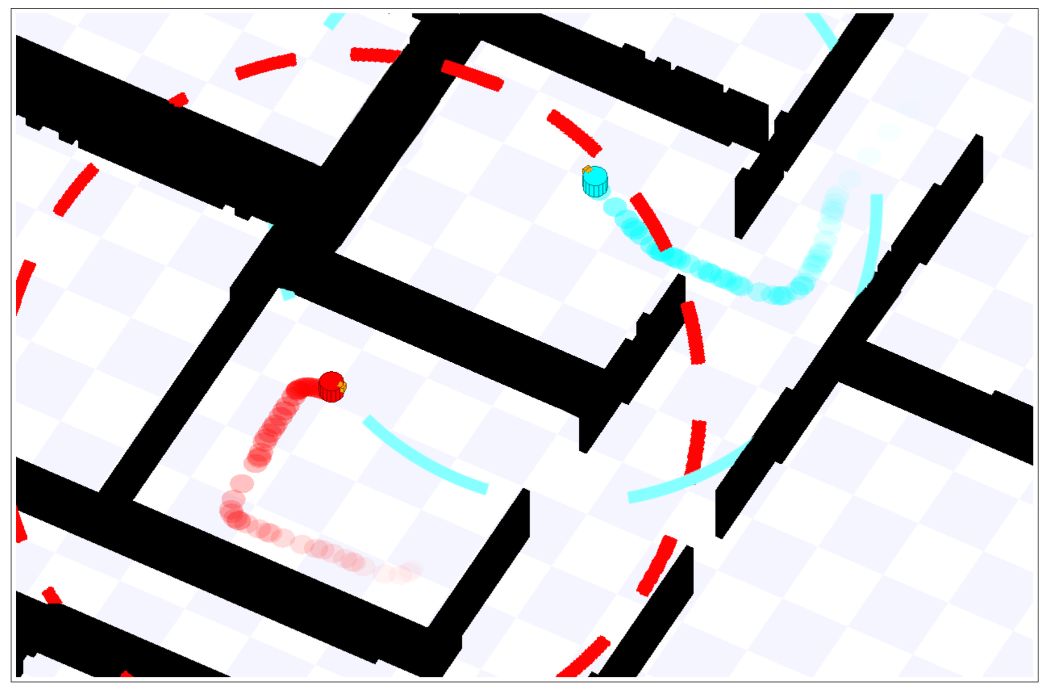
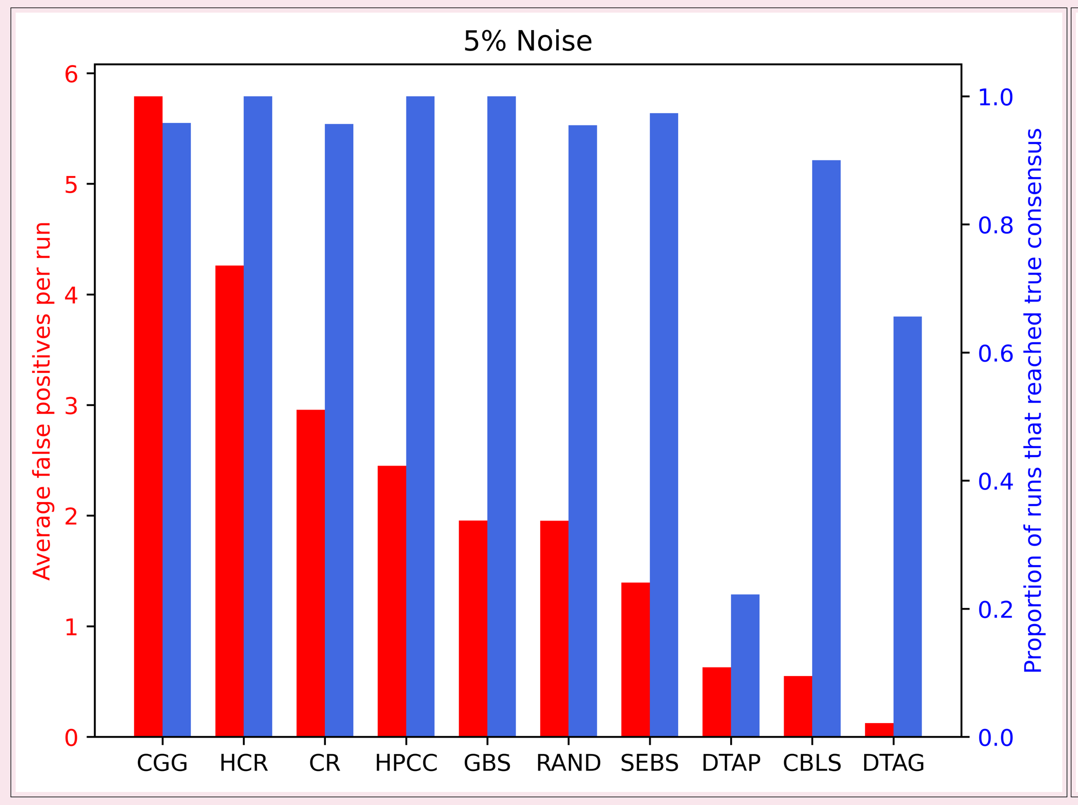
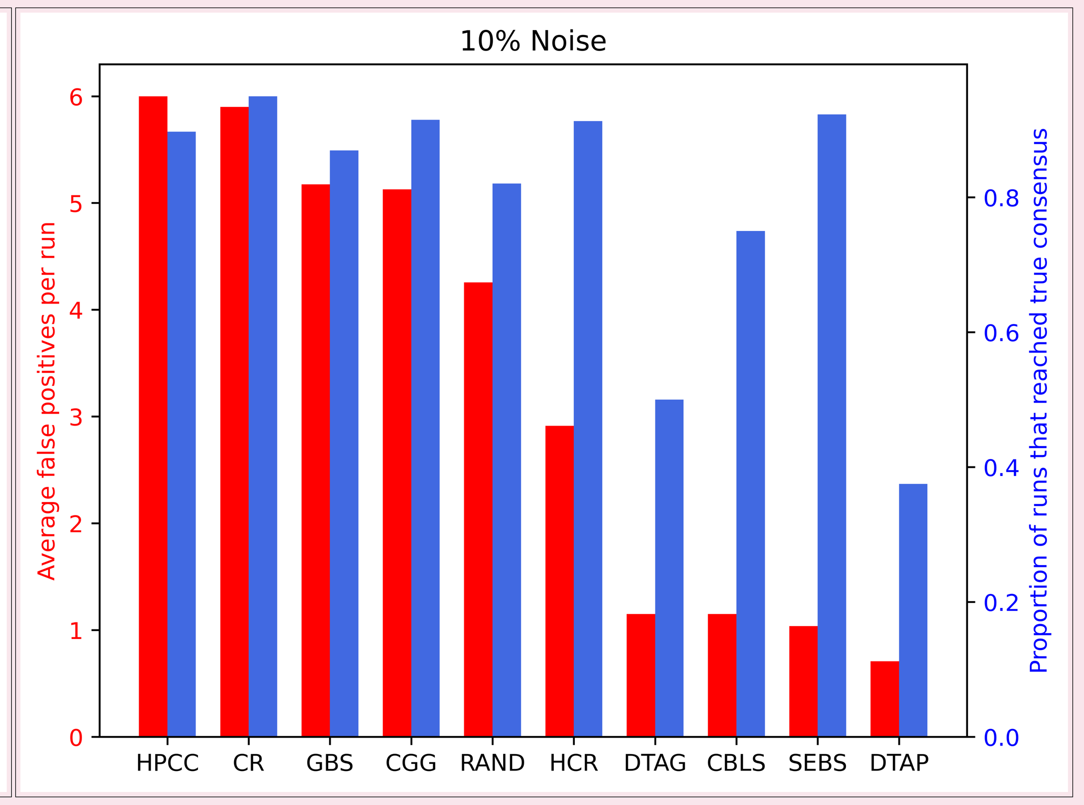


Figure 2: Communication radii of two robot agents patrolling.

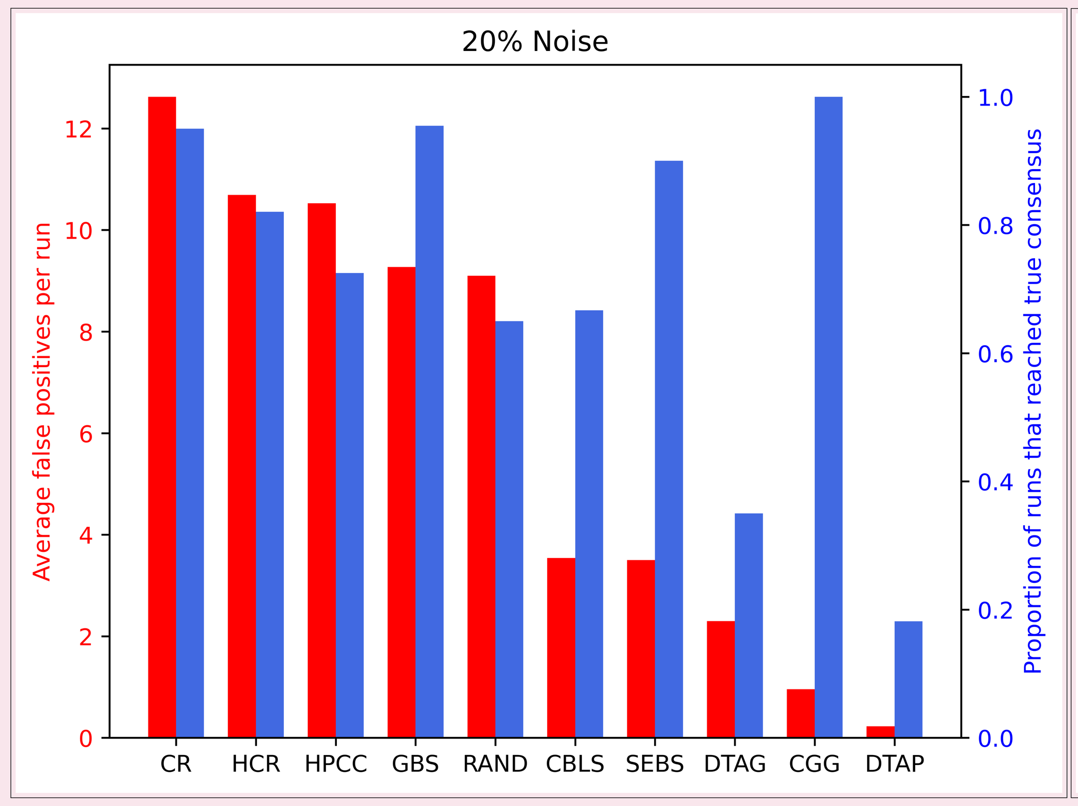
Anomaly True and False Positive Results Ranking



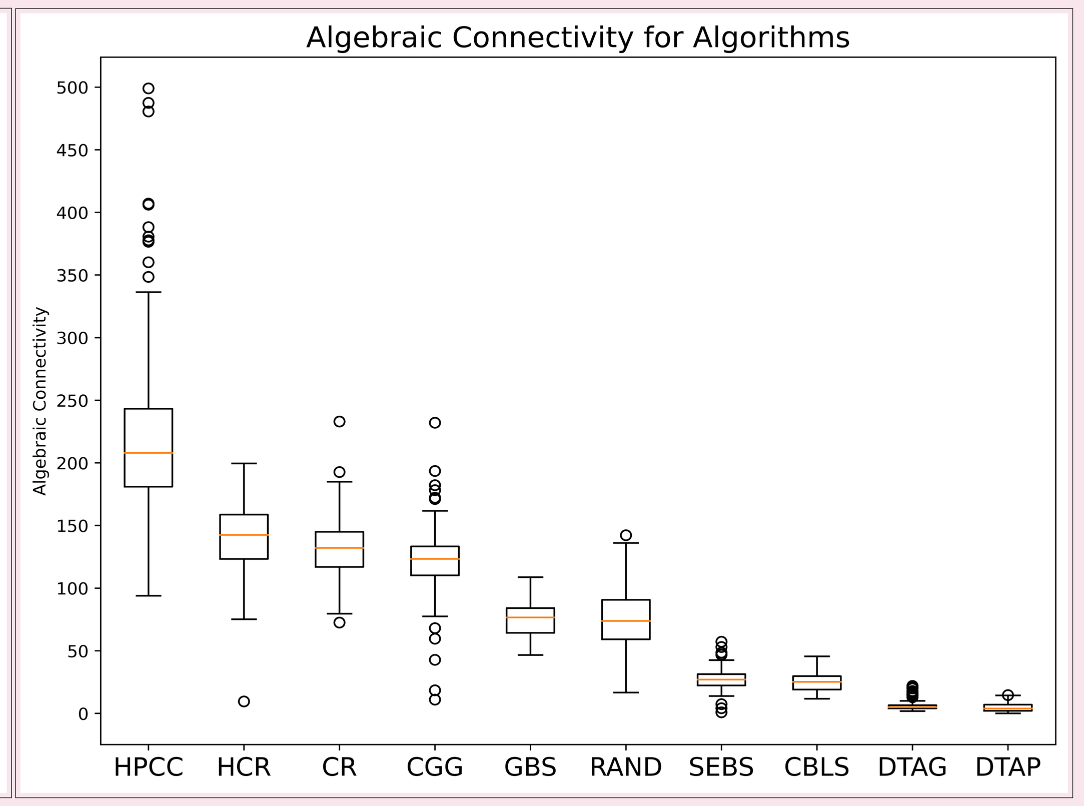
(a) 5% Anomaly measurement noise



(b) 10% Anomaly measurement noise



(c) 20% Anomaly measurement noise



(d) Boxplot of Algebraic Connectivity for algorithms

Figure 3: Subfigures 3a, 3b, 3c show the ranked average performance of patrolling algorithms for different levels of measurement noise across 20 experiments. Red axis is the average count of false positives during a patrol run; blue axis shows proportion of runs that reached consensus on the particular node containing the anomaly. Subfigure 3d: Algebraic connectivity for each tested algorithm ranked.

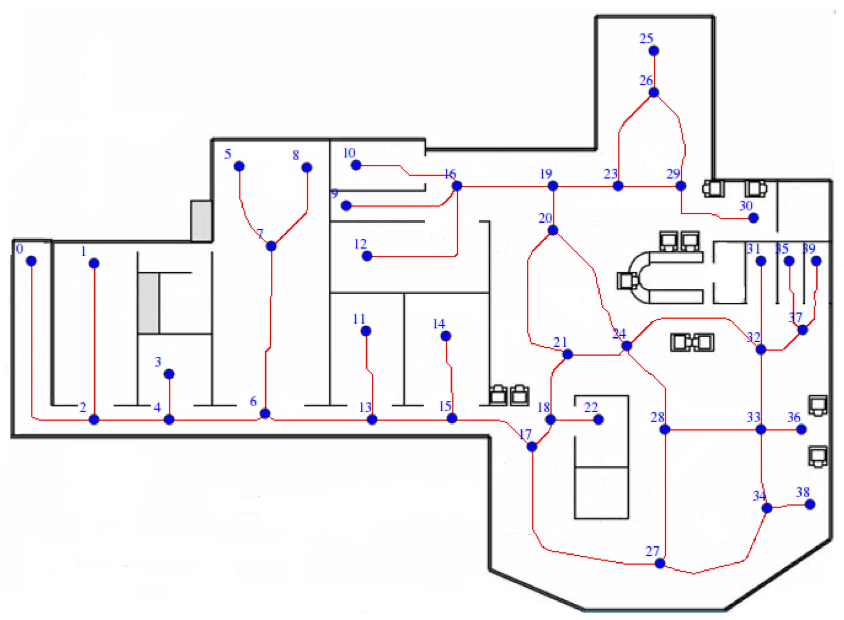


Figure 4: "Cumberland" map graph with 40 nodes.

Algorithms Examined

Short name	Communication	Decentralized?
CBLS	Coordination	Yes
CGG	None	No
CR	None	Yes
DTAG	Coordination	Yes
DTAP	Coordination	Yes
GBS	Idleness	No
HCR	None	Yes
HPCC	None	Yes
RAND	None	Yes
SEBS	State	Yes

Table 1: Multi-Robot Patrol algorithms examined

Results & Discussion

We examine the behaviour of the patrolling algorithms by interpreting their differences in algebraic connectivity of the emergent communication networks between the agents. We calculate an *F-score* to quantify the performance, which provides a metric that weighs the agents' correct (true positive) and incorrect (false positive) beliefs about the world. It is noted that algorithms that result in moderate levels of algebraic connectivity in the communication networks are robust to noise levels and result in high F-scores, this behaviour is also observed in [2]. The performance of these algorithms are highlighted in Table 2. Not only are these algorithms able to accurately reach a consensus on the anomaly, they also record low numbers of false positive events even as the measurement noise increases. We note that the algorithms that exhibit the highest communication connectivity (most inter-agent mixing), record the worst performance in regard to number of false positives.

Algorithm	F-Score							
	0% Noise		5% Noise		10% Noise		20% Noise	
	Avg.	σ	Avg.	σ	Avg.	σ	Avg.	σ
CBLS	0.962	0.0145	0.949	0.0124	0.916	0.0265	0.871	0.0210
CGG	0.954	0.0323	0.928	0.0462	0.931	0.0217	**0.962**	0.0257
CR	**0.974**	0.0008	**0.952**	0.0167	0.923	0.0181	0.860	0.0314
DTAG	0.914	0.0646	0.910	0.0828	0.883	0.0595	0.818	0.0633
DTAP	0.867	0.1291	0.839	0.1312	0.880	0.0764	0.852	0.1057
GBS	0.962	0.0000	0.951	0.0122	0.924	0.0251	0.875	0.0391
HCR	0.956	0.0200	0.933	0.0275	**0.944**	0.0335	0.872	0.0372
HPCC	**0.974**	0.0000	0.951	0.0165	0.922	0.0361	0.881	0.0339
RAND	0.954	0.0025	**0.953**	0.0129	0.918	0.0260	0.868	0.0314
SEBS	0.970	0.0142	0.935	0.0377	**0.936**	0.0242	**0.902**	0.0547

Table 2: Table of performance for patrolling algorithms under different noise levels, with best two performing algorithms in each noise level bolded.

References

[1] David Bina Siassipour Portugal.
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[2] Mohamed S. Talamali, Arindam Saha, James A. R. Marshall, and Andreagiovanni Reina.
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