Distributed Formation Planning for Robot Swarms

I. INTRODUCTION

When many robots need to work together, coordination is required for the planning of safe and smooth paths around each other while avoiding dynamic obstacles in the environment. Robotic swarms can achieve fidelity in tasks, and it is beneficial for robots to remain in formations. To change between formations careful coordination is required, and the calculation of paths can become a limiting factor if real-time movement is required in large scale systems. A distributed system is therefore necessary to ensure scalability in large swarms.

Using Gaussian Belief Propagation for planning, we improve upon previous work by allowing robots to select their own goals, if a global desired formation is known. The formation is defined as a set of target locations, to which all robots are attracted. This allows flexibility in the path planning, as robots can ‘push’ or negotiate for other robots to move out of the way if necessary.

As this is one of the first works using distributed graph algorithms for motion planning and swarm formations and we hope the demos shown here can develop more research in the field.

II. FORMAT OF DEMOS

We will present a number of demos in the form of pre-recorded videos as well as **real-time simulation**, with **user interaction**.

This will be accompanied by a brief spoken introduction to Gaussian Belief Propagation and its application to multi-robot planning and swarm robotics. The accompanying poster would show the formulation of the relevant factors in the factor graph.

III. BACKGROUND

The multi robot planning problem has previously been formulated as a factor graph, where the variables represent robot states at various timesteps in a short forward time window [1]. The variables are connected with factors that represent cost functions relating to the robot dynamics model as well as collision avoidance.

Using Gaussian Belief Propagation the global factor graph (containing the planned paths of all robots) is split into smaller fragments pertaining to the planned paths of each robot. Iterative message passing within and between the factor graph fragments allow for smooth, safe and efficient paths to be planned.

We extend the work and include new types of factors in relation to swarm formations. In addition, we create inter-robot factors between the horizon states of the robots – this allows robots to negotiate and choose their own goals in response to their neighbours and the global task at hand. This allows for many more swarm scenarios with the choice of appropriate factors.

IV. OUTLINE OF DEMOS

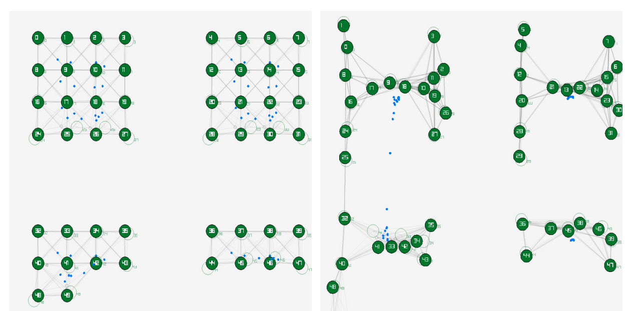
Shown here some examples of the demos that we propose to show.

A. *Shape Formations and Transitions*

1) : The user can input a pre-defined formation shape that all robots know, it may or may not be globally anchored. In the former setting, robots are seen to switch efficiently between two formations smoothly as seen in Figure 1.

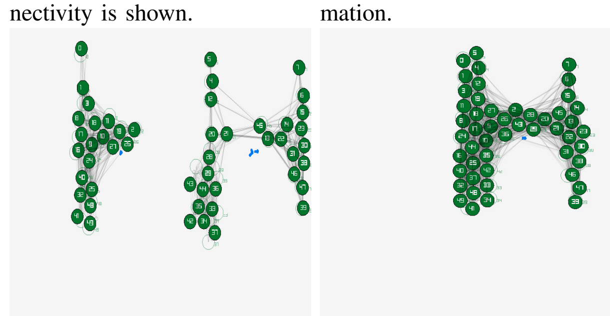
Fig. 1: Robots in a ‘letter A’ formation smoothly plan paths to a ‘letter X’ formation.

2) : In the latter, robots assume the formation is centred at their local centre of mass of their neighbours. In this way emergent behaviour can be seen as in Figure 2, where smaller formations merge into a large formation.



(a) Robots begin separated into local regions, inter-robot connectivity is shown.

(b) Local clusters create small versions of the ‘letter H’ formation.



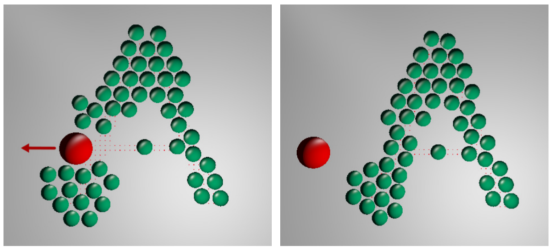
(c) Robots come into contact with robots from other clusters and begin merging into a large formation.

(d) Robots have merged small formations into a large formation.

Fig. 2: Local sensing robots creating the ‘letter H’ formation, eventually merging to create a large scale formation.

B. Obstacle Avoidance

1) : Robots can also be assumed to sense environmental obstacles, static and dynamic, and can move around them whilst rejoining the formation. This is shown in Figure 3 where robots in a formation regroup after an obstacle has broken the formation.

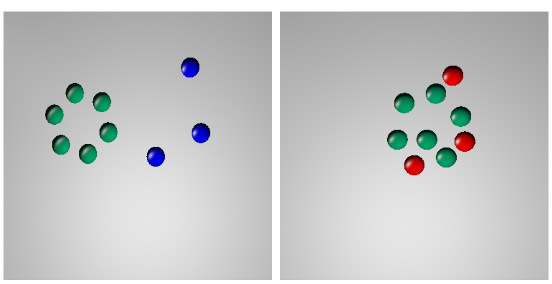


(a) (b)

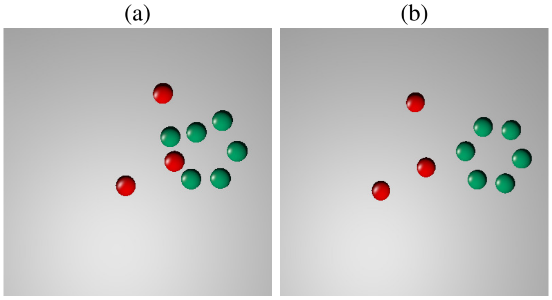
Fig. 3: Robots in a 'letter A' formation move out of the way for an obstacle (red) travelling leftwards. After the obstacle has passed the formation appears to 'self-heal'.

C. Rigid Formations

1) : By encoding 'rigid link' factors, we impose a constraint on robots to keep an ideal distance from another. In this way we can enforce positional formations, such as simple hexagons. By changing the strengths of the constraints we can influence whether the formation as a whole rigidly moves around the obstacles. This is an alternative way for the swarm to avoid obstacles as seen in Figure 4.



(a) (b)



(c) (d)

Fig. 4: Hexagonal formation (green) moving left to right around obstacles (flashing blue/red). Strength of the rigid-link inter-robot factors mean that the formation is able to morph shape temporarily to avoid the obstacles.

V. CONCLUSIONS

This is one of the first works using distributed path planning and communication in the realm of swarm robotics, especially using Gaussian Belief Propagation (GBP).

We hope that the demos shown at the workshop will demonstrate the powerful techniques that GBP can provide to the domain of path planning and formation building. We hope that the demos will serve as an inspiration for more researchers (from all backgrounds) to dive into the fields of path planning and distributed graph algorithms.

REFERENCES

[1] Aalok Patwardhan, Riku Murai, and Andrew J. Davison. Distributing collaborative multi-robot planning with gaussian belief propagation. *IEEE Robotics and Automation Letters*, 8(2):552–559, 2023.