Heuristic Formation Control in Multi-Robot Systems Using Local Communication and Limited Identification

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Motivation

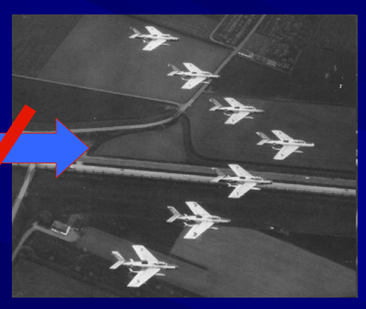
- Formations allow orderly movement of a group while positioning individuals in a useful manner
- Formations may be adopted because of useful defensive or offensive positioning, aerodynamic effects, natural division of individual sensory focus, or other reasons




- Similar reasons for use in groups of autonomous systems

Limitations in Prior Work

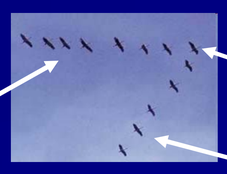
- Most work in formation control ignores the fact that formations in nature are rarely perfect. While we describe a v-formation as common in bird migrations, for example, these rarely achieve geometric perfection:

- When a flock of birds forms a V, local formation rules do not dictate the precise angle, nor the number on each side – flexibility allows local rules to be simpler and should make creating and maintaining the formation more robust
- Prior work is limited in only considering relative distance [Yamaguchi97], assuming homogeneity, knowledge of the number and position of other agents [BalchArkin98], assuming universal knowledge of unique IDs [FredslundMataric02], tying heterogeneity to specific roles [Howard06], relying on a lead agent [Hattenberger07]
- Our work involves creating formations ***heuristically*** in ***heterogeneous*** groups using local rules and local sensing, while avoiding assumptions limiting other approaches: ***no broadcast communication***, ***no universal knowledge of ID***
- Our approach also allows ***adding new members*** because there is no assumption of ID knowledge, group size

Describing Formations

- Every formation consists of a number of ***Formation Conditions***. Each specifies a particular relationship between two neighbours
- e.g. a V consists of 3 formation conditions depending on agent's position:



3. Center agent follows no one

1. Angle/distance relationship on "left" half of V

2. Angle/distance relationship on "right" half of V

Joining a Formation

- An agent attempts to join a formation when it encounters another agent (its nearest neighbour). It queries this agent (possible only if this agent's ID is known) for advice on how to position itself
- Neighbour responds with probabilities indicating which formation condition(s) best describe that which should the querying agent should occupy *if it follows this neighbour*
- Each formation condition thus consists of a vector specifying ideal angle and distance to nearest neighbour, and list of probabilities (1/formation condition) describing probability that condition correctly defines how a querying agent should position itself
- Every formation also has a ***null*** condition, which is followed in the absence of any other information (no visible neighbours, inability to communicate)
- e.g. for a V formation:

Condition	Name	Angle (degrees)	Distance (metres)	P1	P2	P3
1	Right	30	2	1	0	0
2	Left	-30	2	0	1	0
3	Center	–	–	0.5	0.5	0
4	Null	–	–	0	0	1

- Only condition in a V with an alternative is the middle position; other (e.g. Diamond) offer more choice points. Here the null condition starts a new V, which might later merge into other V's created among a group

Identification & Communication

- Our approach supports heterogeneity in sensing: ***not every agent has the ability to perceive the identity of others***
- No broadcast communication: all communication must be addressed (messages contain sender's ID, so it is always possible to reply)
- To allow agents that cannot perceive the ids of others to communicate and properly join a formation, a method is needed to allow agents that can observe IDs to spread this information through the population
- This is done through ***capability*** messages: querying sensory abilities of encountered agents. If an agent states it cannot perceive IDs, IDs and relative positions of those around the agent are sent to it
- Thus, if an agent cannot communicate to its neighbour(s), it may in future be able to as the result of this assistance
- An agent that cannot communicate can still join the formation by selecting a random formation condition – makes the formation approximate but still allows others to join
- When IDs are communicated to the agent, it can query neighbour for the most appropriate condition and adopt it; this can cascade and correct formation imperfections

Robustness

- If an agent is lost, the agent immediately following is can no longer follow the correct formation condition

1. This agent will adopt the null formation condition (e.g. be the center in a new single-agent V formation)
2. Encountering another agent will initiate the formation-joining approach described earlier
- New formation conditions can be propagated to followers of an agent that shifts position (e.g. switching sides of V)

Implementation

- Implemented using simulated Pioneers in Player/Stage
- Subset of population has laser scanners that can read fiducials identifying robots (i.e. can perceive agent IDs)
- All agents use similar devices to determine distance and angle to one another and obstacles
- A common goal and the ability to self-localize are given for the purposes of formation movement
- Agents are behaviour-based [Arkin] with 3 behaviors: ***Avoid-Obstacles, Keep-Formation, Move-To-Goal*** Each generates a movement vector and these are blended in a weighted fashion (3,1,2 respectively)
- Messages are passed through a communications server restricting range and introducing faults
- In addition to messages noted earlier, there is also a *heartbeat* message, sent to neighbour to note continued functionality. Basis for discovering agent failure

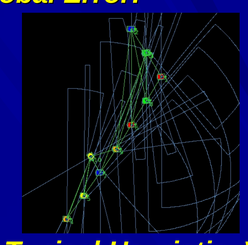
Evaluation

- Ran a series of trials to examine the approach and effect of locality in communication and #agents able to perceive IDs. Tracked two types of error:
- ***Local Error:*** an agent following a formation condition that has zero probability given that of its neighbour
- ***Global Error:*** difference from ideal formation of size n (size - #agents in positions consistent with formation)
- ***Line formation with 5 members:*** 58-64 seconds to form, no impact on # agents sensing IDs, and no errors (only a single formation condition)
- ***V formation with 10 members; Global Error:***

Number of agents who can sense Ids	Trial 1	Trial 2	Trial 3	Trial 4
10	1	4	4	4
5	4	4	2	2
0	3	4	4	3

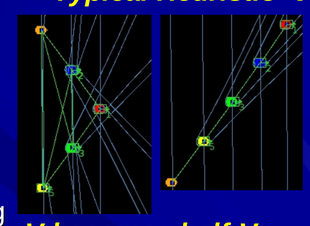
- ***Local Error:***

Number of agents who can sense Ids	Trial 1	Trial 2	Trial 3	Trial 4
10	0	0	0	0
5	2	0	1	2
0	2	1	1	2



Typical Heuristic V

- > ID-sensing agents results in ***smaller*** local, ***greater*** global error, eventually producing more half-Vs
- If communication is perfect, any encountered agent will direct a newcomer down one side of a V. Basis on following makes it unlikely an agent encountering the middle will move up to change sides



V becomes half-V with too much ability to communicate

- Formations generated with little ID-sensing more prone to sudden change: neighbours' IDs cannot be determined without an observer

Ongoing Work

- Currently, heuristic element in formations results from uncertainty as to optimal formation condition for any individual agent. We are moving to imprecise distance and angle descriptions in formation conditions as well
- Implementing this on Citizen Eco-Be (V2) Robots. Using a Mixed reality environment allows consistent evaluation through virtual obstacles, varying terrain, and allows virtual actions to support heterogeneity despite physically similar robots