Towards Automatic Design of Controllers: Implementation of a Neural Network Controller Behavior using Khepera IV Robots

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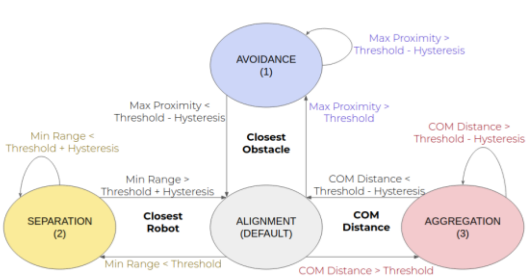
Multi-robot systems have the potential to provide solutions to various problems that would be infeasible or too complex for a single robot to solve, but it is a challenge to manually design controllers for such systems. In this project, controllers for multi-robot flocking behavior were generated using machine learning methods.

For this purpose, distinct neural network controllers for three basic flocking behaviors of aggregation, separation and velocity alignment, together with obstacle avoidance, have been trained using Particle Swarm Optimization. The controllers connected the low-level sensor inputs (range and bearing measurements and proximity sensors) to low-level actuator outputs (left and right wheel velocities). These behavioral components are combined with a manually implemented finite-state machine (FSM) arbitrator to generate overall flocking behavior.



Finite-state machine structure, where each basic behavior is realized with a neural network controller.

Among these behaviors, alignment was the one that was the most complicated to train and yielded the most interesting results. Rather than explicit velocity averaging and matching as usually done in manual implementations, the neural networks of varying sizes for alignment, trained with a wide range of settings, have all learned to move in a particular formation to realize velocity alignment, in which disturbances in formation were rapidly eliminated by displaced robots returning to their original positions following a simple set of rules. This behavior, while demonstrating a robust and perfect velocity matching, has some limitations originating from the fact that it is dependent on the specific formation, such as being only partially scalable.

Learned formation for the alignment behavior and a returning displaced robot.

The success of individual basic behaviors initially did not hold in their combination within the FSM, resulting in endless state transitions due to particular action patterns in the alignment behavior. To eliminate these patterns and fine-tune the controller to obtain a robust behavior, alignment controller was further trained within the FSM, fixing the controllers for the other behaviors. The resulting flocking behavior was smooth and able to navigate without dispersing in the presence of obstacles in the arena.

The work in this project has important implications. Most notably, it was seen that automatically generated controllers can find simpler rules that realize a desired behavior compared to manual implementations. Moreover, it shows the importance to train simple behavioral components within the overall framework as there is no guarantee for individual behaviors to work in harmony in combination with other components.