# Using a Graph-Based Controller to Generate Flocking Behavior

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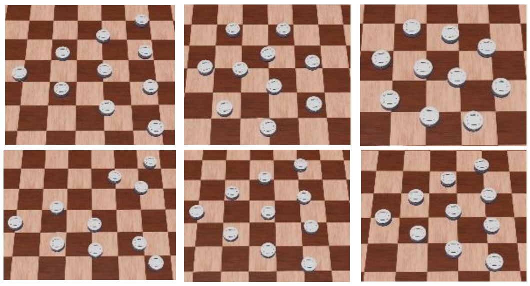
In recent years, multi-robot systems (MRS) have gained importance as coordinated teams are able to perform tasks which would be unfeasible for single robots. Additionally, their inherent redundancy introduces robustness to the system allowing to successfully complete the mission's objective even when some individual agents fail. Spatial coordination of MRS is crucial in a wide range of applications, including surveillance, search and rescue missions, payload deliveries and spacecraft formations. There exist two main categories of algorithms addressing this challenge: flocking and navigation in information. This semester project proposes three new hybrid algorithms: *Lapl2Flock*, *Pot2Lapl*, *Flock2Lapl* for non-holonomic robots, based solely on local information, allowing a gradual shift from rigid to loose navigation in formation and vice-versa. The motivation for this work is to be able to use the advantages of both types of strategies depending on the situation. For instance, a flexible formation (i.e. flocking) would be suited to smoothly navigate in cluttered areas whereas a tighter one might be required in open spaces or urban setups.

The main idea of the *Lapl2Flock* algorithm is to start from Laplacian control and loosen the formation by introducing a circular zone around the agent's desired formation position in which the constraints imposed to the robot are relaxed. By increasing or decreasing the zone radius, the formation is loosened or tightened respectively. Conversely, the two other algorithms, namely *Pot2Lapl* and *Flock2Lapl* are based on flocking incentives combined with additional team objectives allowing to tighten the formation. The idea is to have the real agents follow standard flocking rules while being attracted to virtual holonomic agents following Laplacian control. Then, varying the attractive weight towards the virtual agents allows to gradually shift between pure flocking (i.e. if the virtual agents are completely ignored) and formation control (i.e when the attraction towards the virtual agents dominates the flocking urges). In *Flock2Lapl*, flocking is implemented according to the well-known Reynold's rules. In Pot2Lapl, flocking is obtained using a graph-based approach with a potential function coupled to a velocity matching protocol. The idea is to obtain attractive and repulsive incentives by introducing a potential function with a minima at the desired inter-robot distance and follow its negated gradient.



*MRS composed of ten non-holonomic agents. Left column: Lapl2Flock with a zone radius of 0 (top) and 0.2m. (bottom). Center and right columns: Flock2Lapl and Pot2Lapl with a virtual agent's weight of 0 (top) and 2 (bottom) respectively.*

Besides, this work thoroughly analyzes the potential function of the well-established Olfati-Saber model which has two minia, one at the desired inter-robot distance and another one at the cut-off range of the potential function. To deal with this multiple minia drawback, an alternative potential function is proposed with a single minima at the desired inter-robot distance ensuring the convergence of the robots to the unique minia while conserving the cut-off range. Additionally, for each algorithm, the robot's position in the formation is optimally assigned at every time step to minimize the overall distance traveled to reach the desired formation. The weights of the Laplacian matrix are also dynamically updated at every time step to reduce the probability of flock splitting.

This work demonstrates through quantitative results, obtained in a high fidelity robotics simulator, that all three algorithms reach their objective. Qualitative results show that the robots are able to navigate smoothly and naturally in cluttered environments. Finally, the promising results motivate the future implementation and testing of the hybrid algorithms on real robots.