Preface

Formation control in MASs has received a great deal of attention during the past two decades. Formation control has found different applications including formation flight, transportation engineering, air traffic control, missions in hazardous environment, environmental sampling, and gaming. Some advantages of collaboration among the agents and preserving a formation are reducing cost of the system, increasing robustness and efficiency of the system, and having better fault tolerance, structural flexibility, and capability of reconfiguration. The most recent algorithms for formation control are consensus algorithm, partial differential equation (PDE)-based, and containment control. These approaches, which have been inspired by heat diffusion problems, are interesting because they apply Laplacian control to achieve a global coordination among the agents through local interagent communication.

I started my PhD research by studying features of these three promising methods. After coming to a deep understanding of the fundamentals of these approaches, I attempted to find solutions for the following three problems:

Avoidance of interagent collision: The consensus model and the containment control method can theoretically address stability of evolution of an MAS when all communication weights are positive. However, avoidance of interagent collision among the agents is not necessarily assured, during a transition, for a defined fixed interaction topology with a positive set of communication weights.

Rigidity of MAS formation: For motion control applications when an MAS is applying the consensus model, interagent distances in the desired formation asymptotically converge to constant values. This will result in rigidity of the desired formation, and therefore, collective motion of agents may be difficult where passing through a narrow channel is required.

Containment during evolution: Followers of an MAS evolving under the PDE-based approach or containment control model may leave the containment region, prescribed by the leaders, during evolution (transition), although they are ultimately placed inside the convex hull which is defined by leaders. Thus, collision with obstacles may not be avoided.

It has been demonstrated how these problems can be addressed by treating motion control as continuum deformation. A leader-follower algorithm that is based on continuum mechanics principles can solve the aforementioned. Under a continuum deformation, no two particle agents occupy the same position during evolution, while the MAS has the capability of large expansion and compression. As a result, interagent collision can be avoided. A specific class of deformation mappings that are called homogeneous is considered, where the Jacobian of the mapping is only a function of time and is not spatially varying. A homogeneous transformation of an MAS in an *n-D* motion space can be uniquely related to trajectories of $n+1$ leader agents, where leaders' trajectories are chosen such that collisions with obstacles are avoided. Then follower agents can acquire the desired homogeneous deformation map (prescribed by leaders) either 1) through no interagent communication by knowing leaders' positions in a finite horizon of time or 2) local communication with some adjacent agents and applying different communication protocols. Additionally, it can be shown how an arbitrary distribution of an MAS can be deployed in any desired formation through local communication (with communication weights that are determined based on positions of agents in the desired configuration) where avoidance of interagent collision during evolution is properly addressed.

Also, the issues of robustness to communication failure and asymptotic tracking of desired positions can be addressed when an MAS evolving in an *n-D* motion space applies either fixed or switching communication topologies. Furthermore, the effect of communication delays in an MAS evolving under consensus algorithms or homogeneous maps is another interesting topic. For an MAS containing a large number of agents, the order of the dynamics of MAS evolution is high, and therefore, available methods for stability analysis of delayed systems may be inefficient. To deal with this issue, a formulation for maximum allowable communication delay on the basis of Eigen-analysis of the network Laplacian matrix will be proposed.

I would like to express my deepest gratitude to my parents for their unfailing love, encouragement, and supports. I would also like to thank my sister and brothers. They were always supporting me with their best wishes.

I would never have been able to finish this work without the unsurpassed knowledge and generous and inspiring supports of my beloved advisor, the late Professor Suhada Jayasuriya. I am so proud of being his last student. I will never forget the life lessons that I learned from him. He was a real gentleman with a very kind soul. I am still very saddened by missing such a great father.

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