Cooperative Systems and Pursuit-Evasion

Chris Arney, Army Research Office, Research Triangle Park, NC
Ryan Slocum, United States Military Academy, West Point, NY

Pursuit and evasion are simple ideas involving movement of participant players. In the predator-prey relationships in the natural world, pursuit and evasion is the very essence of survival. While the overall concept seems simple to comprehend and is intuitive to humans, understanding the details of the actions and implementing optimal (or even competent) pursuit and evasion strategies in algorithms is complex and challenging. Finding proper metrics for the measurement of models seems equally difficult. Classical pursuit-evasion modeling and algorithm development has always been of interest to mathematicians and the military. On the mathematics side, differential and difference equation models were directly formed from physical relationships and sometimes solved in closed-form, and, as the models were refined and amplified, approximations were made to solve the more sophisticated models. Further analysis led to optimal solutions for special cases. On the military side, the pursuit-evasion models helped to develop control systems for target-tracking missiles and to develop evasion controls and maneuvers for high-speed combat aircraft. Often, assumptions made for these phenomena were severely limited and therefore the models were naïve -- one pursuer and one evader or possibly a handful of one or the other and simple or non-existent maneuver constraints for the participants. Very seldom were realistic constraints or tangible scenarios successfully considered. Very seldom was a coordinated pursuit or evasion (collaboration or cooperation) considered or were models developed for combatants who sought to pursue but evaded only as necessary (alternating roles of pursing and evading). Despite the simplicity of the assumptions and models and the depth of the research on this problem, there remain many unresolved issues in naïve pursuit-evasion, such as realistic inclusion of goal-seeking participants (evade only as necessary while still seeking to reach a specified goal), optimal methods of movement and operation (except in special cases), under what conditions is capture by the pursuer guaranteed as well as conditions for guaranteed escape by the evader, and most importantly, what are the proper performance metrics to measure and understand as algorithms are developed.

As we approach an era of robots, UAVs, UGV, and UUVs and information significance in military operations, there are many more scenarios of pursuit-evasion to consider with mathematical modeling and analysis. Certainly, complex systems of many pursuers and evaders can be envisioned. Coordination and cooperation among the participants of one side needs to be considered and understood. What kind of communication and control are needed to help the participants achieve their goals? Can swarming phenomena be understood and included in the basic models? Are there optimal strategies to follow? Can an intelligent player learn new strategies as the pursuit or evasion takes place and details of the environment are learned? How are these more sophisticated pursuit-evasion scenarios modeled and analyzed and what can we learn now so we can build proper algorithms and equipment (robots) for future success in the new era of military pursuit and evasion. These questions and many others were on our minds as we studied this problem, using a broad set of mathematical modeling methodologies from various areas of mathematics and, in particular, new ideas from the area of cooperative systems. Preliminary results of our work will be presented.