MAT258a Final Project Proposal

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Overview

My research attempts to address problems that arise in interactions between humans and robotic agents. Information exchanges between humans and large swarms of autonomous robots is known as human swarm interaction (HSI) problem. HSI poses a number of unique challenges. For example, an ensemble of agents must communicate its vast amount of sensor information to the human in a way that is tractable and meaningful. Conversely, the human must have the capacity to interact with the swarm through his or her limited number of sensory channels. This problem does not scale linearly as our attention is quickly overwhelmed when presented with large amounts of information. Such a scenario would preclude any decision making advantages that we might be able to offer. In order to simplify human-to-swarm communication, I intend to develop a control policy that will limit the human input to a single channel for a set of non-holonomic, unicycle robots. As a consequence, the ensemble of n agents will be commanded by a single control signal, broadcast to the entire swarm.

Previous Work

Chipalkatty[1] describes a model predictive control (MPC) based algorithm that blends higher level human commands with the lower level autonomous control for a single robot. Given an MPC framework, the typical problem is to determine a sequence of control inputs that will minimize a cost $\mathcal{V}_{N_k}$ over some finite horizon of *k+N-1* steps. Thus, at the k^{th} step, find the sequence $\mathcal{U}_k = \{u_k\}_k^{k+N-1} = argmin\ \mathcal{V}_{N_k}$. The "human in the loop" objective function penalizes deviations from the human input v_i while maintaining the terminal constraints. Such an objective may be described by the squared norm of the difference between the human command and the control input: $\mathcal{V}_{N_k} = \sum_{i=k}^{k+N_k-1} \|v_i - u_i\|^2$. The controller applies the first element in $\mathcal{U}_k$, and then the optimization is performed again for the cost over the horizon of the remaining *k+N* steps. This formulation was shown in [1] to have an analytic solution for a linear system, $x_{k+1} = Ax_k + Bu_k$.

Becker [2],[3] has shown that complete k-step controllability of a ensemble of n unicycle robots is possible. The state evolution of the group is defined by a non-linear system, $x_{k+1} = f(x_k, u_k)$. The parameters v_i and ϵ_i are specific to each agent in the ensemble while $\theta_i(0)$, x_i, and $y_i$are initial conditions.

$$\begin{bmatrix} x_i(k+1) \\ y_i(k+1) \end{bmatrix} = \begin{bmatrix} x_i(k) \\ y_i(k) \end{bmatrix} + u(k) \begin{bmatrix} v_i \cos(\theta_i(0) + \epsilon_i k\phi) \\ v_i \sin(\theta_i(0) + \epsilon_i k\phi) \end{bmatrix}$$

Problem Statement

The purpose of this effort is to simulate a control law that combines the characteristics of each of the methods described in [1],[2], and [3]. Using the concept of Lyaponuv stability, we can define a scalar function $V\colon \mathbb{R}^m \to \mathbb{R}$ that is globally positive definite and whose time derivative is negative semidefinite: $\dot{V}(x_k, u_k) \leq 0$. Becker [3] suggests such a candidate function. My control policy will determine the choice of $\mathcal{U}_k$. The problem may roughly be formulated as follows: Find an optimizer of the MPC cost objective subject to the stability requirements of the ensemble, the dynamics of the ensemble, and the terminal constraint set, X_f .

$$\{u_k\}_k^{k+N-1} = \underset{u_k}{\operatorname{argmin}} \sum_{i=k}^{k+N_k-1} \|v_i - u_i\|^2 \qquad \text{s.t.} \quad \begin{aligned} &\dot{V}(x_k, u_k) \leq 0 \\ &x_{k+1} = f(x_k, u_k) \\ &x_{\mathrm{f}} \in X_f = \{x \mid Mx = b\} \end{aligned}$$

A more accurate formulation may arise during the course of this work. I will simulate the effect of the control policy with the intent of applying the results on the unicycle robots that we have in our lab.

References

[1] R. Chipalkatty, G. Droge, and M. B. Egerstedt, “Less is more: Mixed-initiative model-predictive control with human inputs,” *Robotics, IEEE Transactions on*, vol. 29, no. 3, pp. 695–703, 2013.

[2] A. Becker, C. Onyuksel, T. Bretl, and J. McLurkin, “Controlling many differential-drive robots with uniform control inputs,” *The International Journal of Robotics Research*, vol. 33, no. 13, pp. 1626–1644, 2014.

[3] A. Becker and T. Bretl, “Approximate Steering of a Unicycle Under Bounded Model Perturbation Using Ensemble Control,” *IEEE Transactions on Robotics*, vol. 28, no. 3, pp. 580–591, Jun. 2012.