2016 IEEE International Conference on Robotics and Automation (ICRA)
Stockholm, Sweden, May 16-21, 2016

Using Abstraction for Swarm Control of a Parent System

Kyle L. Crandall *Student Member, IEEE*, Caleb Whitehead, Shuqi Dong, and Adam Wickenheiser

***Abstract*— Swarms of robots have many uses, from exploring an area in a parallel manner to manipulating objects, both on the ground and in the air. In this paper, we consider a class of swarms in which robots within the swarm work together to manipulate a parent system with its own dynamics. Using the process of abstraction, we find a set of variables that represent key elements of the swarm such as its mean position, the variance of the swarm's distribution, etc. Using these variables, we can generate a simplified model of how the swarm interacts with the parent system and design a controller to control the parent system through this abstract state. We show that we are able to use a swarm to regulate the parent system, track a step input, and reject step disturbances in an example problem involving a swarm of robots balancing a plane that is allowed to rotate about an axis through its center.**

I. Introduction

There are many systems that can be broken down into a swarm of homogeneous or heterogeneous subsystems and a parent system upon which the swarm is acting. Examples of such systems include using multiple helicopters to maneuver a load [1], using an array of flaps on an aircraft wing to control the lift and drag forces experienced by the wing [2], or using groups of ground robots to push an object around [3]. This paper presents an approach to controlling such a system through a swarm using abstraction to develop control laws for the swarm. We divide the control problem into two tiers, the parent system and the swarm. The interaction between these two tiers is then modeled and used to develop control laws for each system to control the parent system.

A. *Overview of the Current State of the Art*

A key component to our method is the concept of abstraction. Belta and Kumar demonstrate that the state of a swarm of robots of arbitrary size can be abstracted down to a lower dimensional state that represents key elements of the swarm such as size, position, orientation, etc. A controller can then be developed to track a desired abstract state trajectory [4] [5]. This approach generates distributed control laws; however, these control laws do rely on state information given by a global observer. Each individual node of the swarm is unaware of the exact global state, only the values given by the observer.

There has been some work using swarms of robots to influence a parent system or some aspect of the environment in which they operate. Habibi et al. presented a controller for using a swarm to transport and orient an arbitrary shaped object by surrounding the object with a swarm that constrains the object's motion, allowing the swarm to "grasp" the object [3]. Other researchers have proposed similar grasping methods [6] [7]. Gross et al. use artificial neural networks in combination with modular robots to manipulate an object [8]. This work focuses specifically on "grasping" type problems in a 2 dimensional space where the swarm is used to box in some object and restrict its degrees of freedom in order to manipulate the object as desired. In these grasping approaches, the swarm pushes on the object being transported and relies on the object to push back to maintain the shape of the swarm [3]. Thus contact is assured, and the state of the swarm can be used to estimate the geometry and other aspects of the parent system. These methods are useful when the dynamics, shape, or other characteristics of the parent system are unknown, and they do not rely on the global observer as our approach does. Our approach assumes a priori knowledge of the parent system as well as a global observer for abstracting the swarm. This can be exploited to result in better performance; however, it does require accurate information about the parent system.

A similar problem is using a swarm of UAVs working together to support a load. Goodarzi and Lee present a controller for using a swarm of UAVs to transport a rigid body. They take into account the dynamics of not just the object being transported but also the cable attaching it to the quadrotors. However, they also assume full state estimation and feedback [1]. Klausen et al. present a different approach to this problem. They divide the problem into two parts, path following and coordination [9]. This approach is similar to the method we present in this paper; however, our division of the problem is different. Both of these papers isolate the dynamics of an individual member of the swarm and determine how it needs to move, either with the rest of the swarm or relative to the parent system. Our method isolates the dynamics of the parent system and determines how the swarm as a whole should move to control it. Doing so has the advantage of not assigning any specific trajectory to members of the swarm, but rather evaluating the swarm through abstract parameters.

Another type of system that demonstrates very complex interactions is an array of actuated flaps attached to a skeletal wing frame. As air flows over the flaps, they can be actuated to generate forces on the body. In previous work performed by our coauthor, a controller was designed for an aircraft wing that consists of an array of flaps that allows the wing to alleviate gust disturbances. This work uses full state feedback of the state of the wing flaps and proposes a centralized control approach to the problem, solving for all the flap deflections at once [2]. Boberg et al. present another such system of flaps with the purpose of reducing vibrations in a suspension bridge. Their approach also considers full state feedback and centralized control [10]. These examples propose centralized controllers for regulating the system. The control method we propose could be applicable to such problems using a more decentralized approach. While these centralized approaches work well when computational resources are plentiful enough to calculate the control inputs in real-time, decentralized

KL Crandall, C Whitehead, S Dong, and A Wickenheiser are with the Department of Mechanical and Aerospace Engineering at the George Washington University, Washington, DC 20052 USA e-mail: crandallk@gwu,edu.