Chapter 28
Using Haptic Feedback in Human-Swarm Interaction

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ABSTRACT

A swarm of robots is a large group of individual agents that autonomously coordinate via local control laws. Their emergent behavior allows simple robots to accomplish complex tasks. Since missions may have complex objectives that change dynamically due to environmental and mission changes, human control and influence over the swarm is needed. The field of Human Swarm Interaction (HSI) is young, with few user studies, and even fewer papers focusing on giving non-visual feedback to the operator. The authors will herein present a background of haptics in robotics and swarms and two studies that explore various conditions under which haptic feedback may be useful in HSI. The overall goal of the studies is to explore the effectiveness of haptic feedback in the presence of other visual stimuli about the swarm system. The findings show that giving feedback about nearby obstacles using a haptic device can improve performance, and that a combination of feedback from obstacle forces via the visual and haptic channels provide the best performance.

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INTRODUCTION

A robotic swarm consists of a large collection of simple robots with limited sensing, communication, actuation, and computational capabilities. Individual robots act according to simple local rules and exhibit a wide range of behaviors, such as flocking (Reynolds, 1987; Couzin, Krause, James, Ruxton, & Franks, 2002; Spears & Spears, 2012; Bruemmer, 2002) without any centralized controller. However, for performing complex tasks like search and exploration in obstacle-filled environments, it is usually difficult to design local control laws for individual swarms that guarantee good performance of the overall system. To use swarm robotic systems in a complex mission, the presence of human operators are required to guide the behaviors of the swarm towards accomplishing mission goals. A key aspect of using a human to control a swarm is the transfer of information between the human and the swarm. The human has to obtain information about the state of the swarm in order to control it. In the extant literature, experimental studies in human swarm interaction have primarily explored the use of the visual channel of the human to transfer information about the swarm state. However, the use of the haptic channel has not been studied adequately in HSI, except for formation control tasks and with small multi-robot systems (fewer than 10 robots). Therefore, along with background literature, this chapter will present experiments to explore the benefits of using a haptic device to control swarm robots (in addition to the visual channel), using large numbers of robots to demonstrate scalability.

A key aspect of using a haptic device to feed information back about the robot state is to decide on the information (or cue) that should be fed back from the robots to the human. In many swarm robotic algorithms, potential field based methods (LaValle, 2006) are used for avoiding obstacles. Roughly speaking, when a robot is near an obstacle, the robot controller computes a virtual force from the obstacle that is inversely proportional to the distance (or some superlinear function of the distance) between the robot and the obstacle. Thus, the nearer a robot is to an obstacle, the greater the force it “experiences” that makes it move away from the obstacle. Therefore, one cue that can be fed back to the human is the net obstacle forces experienced by the robots.

In formation control tasks, since the robots have to usually maintain a rigid formation as they move, each robot has to track a path in order to maintain a formation. Thus, a natural cue in formation control is the tracking error of the robots in following their paths. The use of net forces from the obstacles along with tracking errors has been explored in the context of formation control (Son et al., 2011). In many applications of swarm systems, especially in obstacle-filled environments, it is not always desirable to move the robots in a formation. In these cases, there is no natural notion of tracking error, so the force cue from the obstacles can be fed back to the humans through the haptic device instead.

Although feeding back the obstacles forces is conceptually intuitive and computationally simple, it is not clear a priori whether such information is helpful in improving the performance of the human controller. This is because the force fed back is the (vector) sum of the forces acting on all the robots from all the obstacles. Thus, in some cases like moving from a room to another room through a doorway, one should keep pushing in the direction in which the resistance from the haptic device increases (since the resistance would increase initially and then drop as the robots start moving through the doorway). This is not the intuitive form in which haptics is usually used in human robot interaction. The usual intuition in using haptic feedback from obstacles is that one should *not* try to push in the direction in which the haptic resistance is increasing. Furthermore, since the force fed back to the human is an average of the forces from all the obstacles it is not clear whether it is necessary to use a haptic device to feed back the force or whether a visual representation of this force is enough. In other words, it is unclear whether