Swarm Transparency

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ABSTRACT

A key element of system transparency is allowing humans to calibrate their trust in a system, given the implicit inherent uncertainty, emergent behaviors, etc. As robotic swarms progress towards real-world missions, such transparency becomes increasingly necessary in order to reduce the disuse, misuse and errors humans make when influencing and directing the swarm. However, achieving this objective requires addressing the complex challenges associated with providing transparency. Two swarm transparency challenge categories, with exemplar challenges, are provided.

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1 INTRODUCTION

Recent research has focused on how humans can influence robotic swarms in order to achieve the human's desired outcomes [3, 11]. Simultaneously, efforts exist to provide transparency into the capabilities and actions of artificial systems that also increase the human's trust and communication with the system [4]. Swarm robotic systems introduce a unique set of transparency challenges.

Swarms include a large number of individuals (> 50) that interact locally to make distributed decisions, which provides resiliency given that there is no single point of failure. Biological swarms include ant and bee colonies [10, 14], flocks of birds [2] and schools of fish [7]. Swarms differ from traditional organizational structures [1] and social dominance structures in primates [13].

Chen et al. define agent transparency as "the descriptive quality ... to afford an operator's comprehension about an intelligent agent's intent, performance, future plans, and reasoning process." [5]. Chen et al.'s Situation awareness-based Agent Transparency (SAT) framework leverages a situation awareness model [9]. At level one, the agent communicates its status, actions and plans (perception). The agent communicates reasoning processes (comprehension) at level two and projections of future outcomes and uncertainties at level three (projection). The SAT framework increases transparency, benefiting human-robot team performance across several contexts. Dismounted infantry working with a ground robot providing greater transparency positively affected the humans' task performance and trust in the robot, without increasing workload [16].

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As robotic swarms for real-world applications are developed, the ability to provide transparency into a swarm's current and projected state becomes a critical development consideration. Section 2 highlights swarm transparency challenges that result from the basic characteristics of swarms and advanced swarming capabilities.

2 SWARM TRANSPARENCY CHALLENGES

Transparency of swarms is complicated in that there is no single point on which humans can focus in order to identify the swarm's state [3, 15], which aligns with the biological perspective [10]. Thus, swarm transparency requires understanding the collective swarm state. Often, swarm behavior is not the summation of the individual behaviors, but rather emerges. Identifying and understanding how behaviors emerge is challenging. Further, delays and non-linear relationships between human input, the swarm response, and communication back to the human will hinder creating transparency.

2.1 Basic Swarms

Flocks of birds [2] clearly demonstrate the characteristics of basic swarms. Starlings generate ever changing, but incredible formations, while relying on distributed, localized communication, a key component to overall swarm robustness that also hinders transparency. The localized communications maintain a connection between local entities, but the individuals are typically unaware and not in communication with the entire swarm [10].

Individual swarm entities are often modeled as relying on the radii of attraction, orientation, and repulsion [7] to maintain their position within the swarm. Very small adjustments, which can happen quickly, ensure that the swarm maintains its progress, but will be difficult for humans to detect, even in optimal situations that permit perfect communications with each swarm entity.

Large swarms will be challenged to communicate their basic positional information reliably, which diverges from human-robot systems that assume near perfect communications and provide the status of the individual robots' positions and progress. Such traditional status displays are infeasible with swarms. Another wrinkle for swarm status displays is that humans' perceptual systems are unable to track large numbers of individuals [15]. Thus, traditional methods of providing level 1 transparency in multiple robot systems are infeasible. A more cohesive representation of the overall swarm progress is needed. Abstract visualizations [12] may support level 1 transparency, but it is unclear exactly what information needs to be communicated to humans' in order to support transparency.

High information quality and quantity requires reliable and high-bandwidth communication networks, which are generally infeasible with swarms. Thus, human-swarm interaction research has focused on "influencing" elements of the swarm [3, 11]. Unreliable communications leads to two issues. The first issue is related to simply knowing if the command was received. Determining the command's status is further complicated by the second issue, which

is the notion of neglect benevolence [11], or the time between when a human issues a command and the swarm converges and stabilizes in response to the command. Humans expect an acknowledgement. A human issuing commands may not know a) if any swarm members received the command, or b) if the command was received, which members received it. Given the emergent behaviors, issuing the same command in differing circumstances or even to another section of the swarm, may result in different swarm behavior. Thus, the ability to clearly identify that the command has been received and resulted in the desired outcome becomes more complicated.

Slight environmental changes can dramatically change the swarm's response and generate unanticipated emergent behaviors. Divergence from known, or anticipated behaviors may be more frequent or larger if the environment includes dynamic entities unassociated with the swarm that change the environment.

Models and predictive capabilities can remedy some transparency issues [3], but also have limitations. However, the emergent behaviors often improve the swarm's robustness in response to the environment or other disturbances or influences.

2.2 Advanced Swarms

Very simple biological swarm entities do not possess advanced information processing or reasoning, but swarms exhibit what appears to be very intelligent behaviors [7]. This observation is particularly true with honeybees and ants. For example, honeybee explorers routinely reach consensus on a new nest site that meets very clear criteria [14]. These more advanced capabilities will be necessary for swarms to prove beneficial in many domains and circumstances. These advanced capabilities will exceed the capabilities of biological swarms, which will exacerbate the challenges to providing transparency.

Consensus decision making for best-of-N problems is an excellent example of an advanced capability. Efforts to develop similar capabilities for robotic swarms [6, 8] are promising, but the algorithms are often dependent on the environmental circumstances and algorithm elements, such as inhibition by an entity. Thus, the algorithms can choose sub-optimal alternatives. These algorithms can require extended consensus deliberation periods; however, an on-going human-swarm interaction evaluation is demonstrating that even with imperfect or missing information humans can more quickly select the optimal nest. As advanced swarm capabilities are developed, the unanticipated emergent behaviors will likely become more prevalent and divergent from prior behaviors, which will complicate providing transparency into the swarms' status.

More advanced swarm algorithms will generate neglect benevolence conditions due to internal changes. The swarm will require time to transition between the existing and desired behaviors as an individual, or a subset of individuals begins the transition induced by an advanced algorithm. It is possible while transitioning, the swarm may exhibit unrecognizable or unexpected characteristics. This transition state will likely lead to an incomplete state for which it may be difficult to provide transparency, the only solution may be simply communicating that a transition is occurring. A transition lag, similar to neglect benevolence, may be necessary when the algorithm influences the swarm and the human needs to allow the transition to occur in order to not disrupt the outcome [3].

Advanced swarm capabilities can result in the underlying "artificial intelligence" evolving and exacerbate the need to "explain" the outcomes. However, swarm entities are not likely to have significant long-term memory or as advanced reasoning, which coupled with the inability to communicate with all entities of the swarm will hinder providing adequate explanations and transparency.

3 CONCLUSION

The challenges to providing transparency into the swarm's state, or supporting the human's perception and understanding of swarms as well as the ability to project the future swarm's states arise from a number of factors. Fundamentally, the basic characteristics of swarms, which often emulate their biological inspirations, hinder achieving full transparency. Robotic swarms are anticipated to incorporate capabilities that exceed their biological inspirations, but do not emulate advanced intelligent robot systems. These more advanced swarm capabilities, and the characteristics of the anticipated realistic swarm missions further complicate providing transparency into the swarm's current and projected states and behaviors.

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