Explicit and Implicit Directional Information Transfer in Collective Motion

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We study the cohesive coordinated collective motion of a group of mobile autonomous robots. We use virtual interactions between robots implemented via proximal control, a method that allows the robots to reach a stable formation using virtual potential functions (Turgut et al., 2008; Ferrante et al., 2011). The alignment component can be seen as a mechanism for directional information transfer (Sumpter et al., 2008). We refer here to information transfer in collective motion as the process through which the orientation of a robot is transferred to its neighbors over time.

In this paper, we design two information transfer mechanisms for collective motion in a group of mobile robots. The first mechanism exploits direct information transfer using communication, and can be implemented on robots equipped with proximity sensors, with an orientation sensing mechanism and with a communication device. We propose communication strategies that allow a group of robots that is informed about a desired direction of motion to influence the rest of the group (Couzin et al., 2005; Ferrante et al., 2011). The second mechanism consists of information transfer without the alignment component and communication (Ferrante et al., 2012), which can be used on simpler robots that are only equipped with proximity sensors. We developed a simple motion control mechanism that allows a group of robots to perform collective motion in a random direction with neither the need of robots informed about a desired direction nor of an explicit alignment behavior. As such, information among the robots is transferred indirectly.

Information transfer via communication

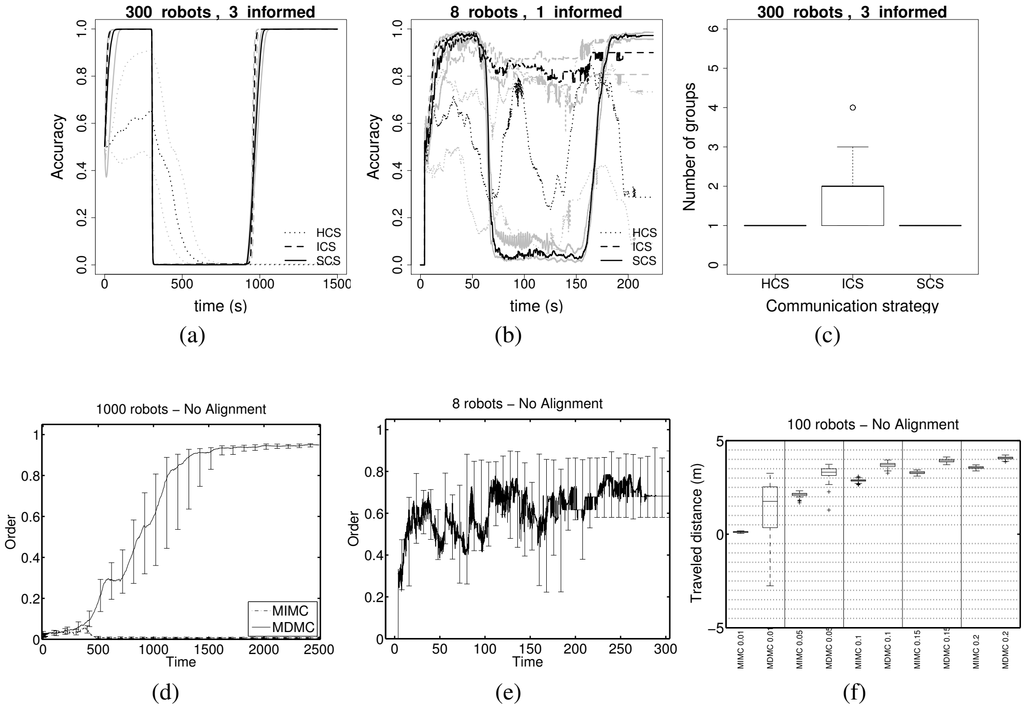
We consider a case where some of the robots have a persistent desired direction of motion (goal direction A), that can be seen as the direction to food source. There is also a second desired direction (goal direction B) only present during a limited time window, that can be seen as the avoidance direction from a predator. Goal direction B is in conflict with goal direction A: it points in the opposite direction and has higher priority to be followed. The objective is to move the group in the direction with maximum priority and to keep the group cohesive.

We proposed a self-adaptive communication strategy (SCS), that is an extension of two previously proposed strategies (Ferrante et al., 2011). In SCS, the focal robot receives the angle information θ_{s_i} from its neighbors. It computes the average of all the received information: $\mathbf{h} = \frac{\sum_{i=0}^{k} e^{j\theta_{s_i}}}{\| \sum_{i=0}^{k} e^{j\theta_{s_i}} \|}$. It also sends angular information to its neighbors: $\theta_{s_0} = \angle \left[w\mathbf{g} + (1-w)\mathbf{h} \right]$. The parameter $w \in [0,1]$ represents the degree of confidence of the focal robot about the desired direction $\mathbf{g}$. Non-informed robots use $w = 0$ (they do not possess information about $\mathbf{g}$). Robots informed about goal direction B use $w = 1$, which makes them stubborn. Robots informed about goal direction A increase w when they measure high level of consensus in the information received by the neighbors, and decrease it otherwise.

Figure 1a shows the distribution of the accuracy over time, measuring how close the group direction is to goal direction A. In the experiments, 1% of the robots is always informed about goal direction A. During the time window where an additional 1% of the robots is informed about goal direction B, the accuracy reaching 0 indicates that goal direction B is being followed. In the remaining part of the experiment, the group correctly follows goal direction A. The result has been validated on real robot experiments (Figure 1b). In the plot, we also report a comparison with the previously proposed strategies (HCS and ICS) and show that, using these strategies, either the accuracy is worse (Figure 1a and Figure 1b) or the group loses cohesion and splits (Figure 1c). The full results are reported in Ferrante et al. (2011).

Information transfer without communication

We consider information transfer without the alignment behavior and without communication. The mechanism we developed is based on a novel motion control method: Magnitude Dependent Motion Control (MDMC). MDMC is used to compute the forward and angular speed of the robot. The two speeds depend on the magnitude and angle of $\mathbf{f}$, the vector resulting from proximal control that encodes the attraction and repulsion strenght from the neighbors. $\mathbf{f}_x$ and $\mathbf{f}_y$ denote the projection of $\mathbf{f}$ on the axis parallel (x) and per-



(a) (b) (c)

(d) (e) (f)

Figure 1: Results of experiments with simulated and real robots (data in (a), (b), (d) and (e) is sampled every second).

pendicular (y) to the direction of motion of the focal robot. In MDMC, the forward speed u is proportional to the x component: $u = K_1\mathbf{f}_x + U$, and the angular speed ω is proportional to the y component: $\omega = K_2\mathbf{f}_y$, where U is a forward biasing speed.

Figure 1 (second row) shows the results of experiments performed with simulated and real robots. MDMC has been compared with the method used in Turgut et al. (2008), that we call Magnitude independent motion control (MIMC). In MIMC, the forward and angular speed do not depend on the magnitude of the vector $\mathbf{f}$ but just on its angle. Figure 1d shows the distribution of the order metric over time, measuring the degree of alignment in the group. MDMC achieves ordered motion without the alignment behavior and without informed robots, whereas the method we compare to does not. We validated these results on real robot experiments (Figure 1e). Additionally, when a proportion of informed robots ($0.01, 0.05, 0.1, 0.15, 0.2$ as indicated in the plot) is introduced, the group, using MDMC, is able to travel further along a desired direction of motion if compared to the method in the literature (Figure 1f).

Discussion

We showed that information needed to achieve collective motion can be transferred either directly or indirectly. Direct information transfer requires robots with orientation sensing and communication devices. We developed a communication strategy that can cope with two conflicting desired directions of motion. We also proposed a novel mechanism for robot motion that explotis indirect information transfer. This allows robots that lack the above mentioned capabilities to perform cohesive collective motion without communication, indicating that implicit information transfer on the heading direction takes place even without communication. Future work aims at utilizing information-theoretic metrics to measure information transfer in a more rigorous manner.

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