Chasing strategies of a flock of drones

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***Abstract*—We present a bio-inspired, agent-based approach to describe the natural phenomenon of collective chasing in two dimensions. Using a set of local interaction rules we show a continuous-space and discrete-time model which $i)$ resembles qualitatively to the general chasing strategies found in nature; $ii)$ is more effective than individual chasing strategies and can be applicable to a wider range of non-trivial situations, e.g. when escapers are much faster than evaders; $iii)$ has optimal chasing parameters that maximize efficiency while minimizing the number of chasers. We present statistical simulation results executed on a framework [8] which was developed directly for the realistic simulation of the collective motion of flying robots. In our simulation we created realistic conditions with delayed communication, noise, limited communication range and acceleration. We implemented and compared special bio-inspired chasing and escaping strategies, like the 'zig-zag' pattern of motion of escapers or the cognitive prediction of escaper motion for evaders. Our final solution is designed to be directly applicable to our quadcopter fleet, too [7].**

The prey-predator systems as theoretical problems have been studied for a long time. If we only focus on the individual-based concepts, we can conclude that the first models [3, 9] mainly used the apparatus of game theory and were trying to give exact, analytical formulas to determine certain properties of the pursuit which required a lot of unrealistic, biologically questionable assumptions. These limitations were broken as the computational capacity was increasing and the cellular automata models with discrete space, time and usually periodic boundary conditions started to spread [4, 5]. They gave the chance for more sophisticated investigations and a much deeper understanding of the underlying dynamics, but they were still too far from the real systems. Finally, the latest paradigm of this field is the usage of physical approaches like continuous space and time or pair interactions between agents having recently been published in a few papers [6, 1].

For relevant biological basis it is important to find some universal aspects of natural predator-prey systems. Numerous biological field-studies have been previously made regarding the habit of certain species, however, only a few of their findings seem to be general, and two of them were implemented in this model. On one hand, it was reported many times that carnivores are trying to encircle their prey [6] (Fig. 1/a). On the other hand, the prey is often trying to escape with 'zig-zag', in others words to spoof their pursuers by sudden changes of direction [2] (Fig. 1/b).

Regarding the weaknesses and strengths of the previous models we built a bio-inspired one on physical basis with soft, circular and finite boundaries and implemented it in our own simulation framework, designed for flying robots. All the agents have finite velocity and acceleration (inertia) and the system is biased with delay. In our case, there is a cohesive pack of predators where the strength of the cohesion ($\gamma > 0$), just as the number of chasers, is characteristic to the chasing strategy. The cohesion is affecting the preferred ($\mathbf{v}_{c,i}^{pref}$) velocity of each (i) chaser in the following way:

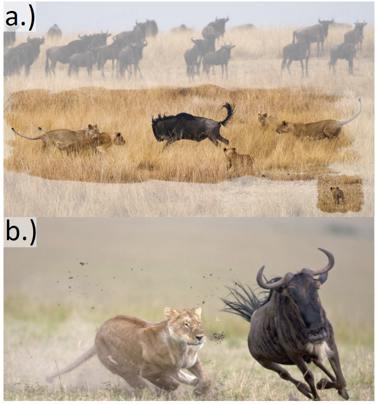

Fig. 1. a.) Lions ($Pantheraleo$) encircling a buffalo ($Syncerus$) [www.federicoveronesi.com]. b.) Buffalo is using the 'zig-zag' tactics [http://2.bp.blogspot.com].

$$\mathbf{v}_{c,i}^{pref} = \gamma \cdot v_{max,c} \cdot \mathcal{N}\left[\sum_{j}^{N_c} \cdot \frac{|\mathbf{d}_{ij}| - \frac{R_a}{\sqrt{N_c}}}{|\mathbf{d}_{ij}|}\right], \quad (1)$$

where $v_{max,c}$ is the maximum velocity of the chasers, $\mathbf{d}_{ij}$ is the relative position vector between two chasers (i, j), N_c is the number of chasers, R_a is the diameter of the arena and $\mathcal{N}[\cdot]$ operator normalizes it's argument as a vector. Here the chasers are trying to catch a single, but significantly faster escaper which is a yet rarely studied scenario in the literature. Chasers are predicting their prey's dynamics based on available local information (Fig. 2). Contrarily, escapers may use 'zig-zag' pattern of motion in certain situations to mislead their evaders (Fig. 3).

We ran each simulation 50 times on a supercomputer cluster to get statistical results of the model with a default delay of 1 s and standard experiment length of 1500 s. We studied $i)$ the proportion of successful chasing events as a function of γ and the number of chasers (Fig. 4.); $ii)$ the effectiveness of the prediction mode (Fig. 5.); iii) and the elapsed time during the pursuit in regard of the 'zig-zag' pattern of motion (Fig. 6.), just to mention a few. We also defined a fitness function of the chasing (Fig. 7.). The analysis of these quantities let us conclude that an optimal group of chasers exists (regarding the

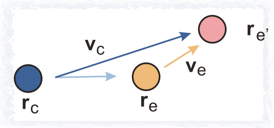

Fig. 2. The coordinates ($\mathbf{r}_{e'}$) where the chaser can catch it's prey (if such a place exists) are approximated, based on the current position and velocity vectors of the c

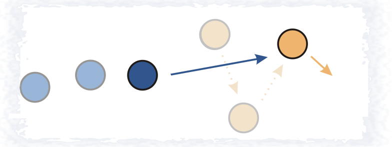

Fig. 3. The escaper is moving with sudden changes of direction which is called the 'zig-zag' pattern of motion.

number of chasers and the cohesion strength) and it always worth to predict the escaper's paths. For escapers, there are distinct domains of escaper-chaser velocity ratio vs. number of chasers where 'zig-zag' pattern of motion is advantageous or not (Fig. 6.), even if the escaper is faster then it's chasers.

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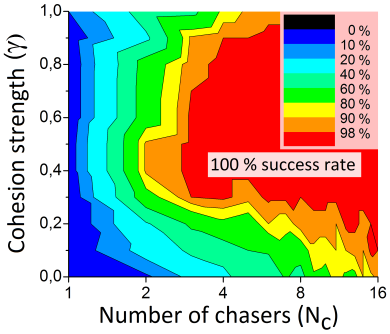

Fig. 4. The proportion of successful chasing events depending on the attributes of the chasing flock.

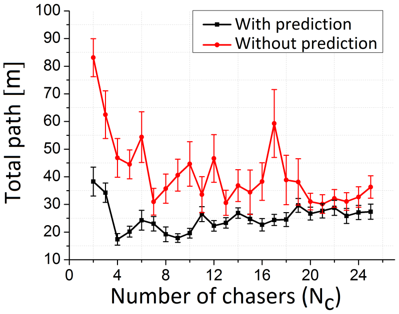

Fig. 5. The total path as linear costfunction as a function of N_C – a comparative example when the chasers are/are not predicting the escapers position.

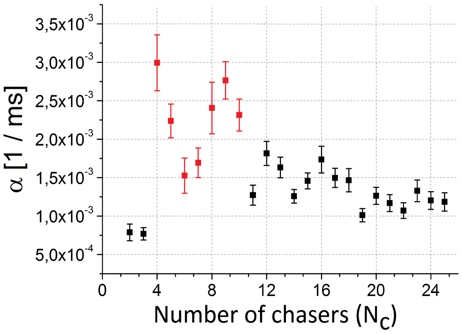

Fig. 6. The fitness of the chasing is defined as the reciprocal of the product of number of chasers (N_c), the time needed to catch the target (t) and the total path of chasers (s): $\alpha = N_c \cdot t \cdot s$.

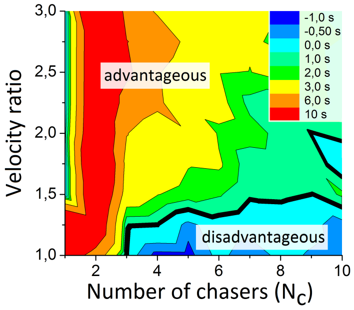

Fig. 7. The difference between the total time of the pursuit with and without the 'zig-zag' tactics as a function of N_c and the chaser's and the escaper's velocity ratio.