Motion control of a population of Artemias

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***Abstract*— In this work, the collective behavior of Artemia Salina is studied both experimentally and theoretically. Several experiments have been designed to investigate the Artemia motion under different environment conditions. From the results of such experiments, a strategy to control the direction of motion of an Artemia population, by exploiting their sensitivity to light, has been derived and then implemented.**

I. INTRODUCTION

Mathematical modeling is the primary tool for exploring the connection between individual properties and group properties in complex systems. Using models, it is possible to test different interaction mechanisms and to emulate the resulting group behavior. Understanding and modeling the relative mechanisms and operational principles of collective behavior of animals has been a source of inspiration for multi-agent control strategies based on decentralized algorithms. In fact, flocking in such models is often ruled by very simple interaction mechanisms which can be efficiently implemented in autonomous robotic units. The study of flocking may therefore provide useful ideas for developing formation control, distributed cooperative control and coordination of multiple mobile autonomous agents/robots [1].

In literature, different models for flocking, and in general collective motion of animals, have been introduced. In 1987, Reynolds introduced a computer model called “boids” that simulates the motion of bird flock or fish school [2]. Each bird has a local control strategy, which however allows the emergence of collective behavior. Another important model for flocking was proposed in 1995 by Vicsek et al. [3], which described the system in terms of self-propelled particles, each of them interacting with the other particles which lie in a given interaction radius of it. The model has been then extended by Couzin et al. [4] which defined three different radii and considered different rules in each of the zones defined by the three radii. Many other papers focus on models of fish school [5]-[8]. A common approach is to derive Newton equations to represent as forces the mechanisms acting on each individual in a flock. In fact, although the time and length scales, such as size, mass and speed, differ tremendously from insects to birds, if the kinetic constraint on the animals, such as viscous or internal force to the animal bodies, is strong, the collective behavior may be expressed in a common framework based on Newton equations.

In this paper, collective behavior of a population of Artemias has been experimentally investigated and modeled with the aim of envisaging possible ways to control them. Artemia belongs to a genus of very primordial crustaceans, which exhibit simple individual behavior. The study of such simple animals provides the possibility to perform simple and low-cost experiments, which allow to investigate experimentally models of complex behaviors and, eventually, to derive simple control mechanisms.

The mathematical model discussed in this paper describes the effect of light intensity on direction of Artemia motions, and the response of a population of Artemias to light wavelength (red, green, blue and white), as observed during a series of different experiments performed in our laboratory. Some results about the effect of DC current, magnetic, electromagnetic field and acoustic signal on the behavior of Artemia are also discussed. Finally, a robot system able to control the Artemias population direction is presented.

II. EXPERIMENTS ON ARTEMIA MOTION

Artemia Salina is a crustacean smaller than insects in size and mass. To perform our experiments, a population of Artemia has been hatched in laboratory. The hatched Artemia is called nauplius, has a length typically less than 0.4 mm and shows an anatomical structure different than that of adult Artemias. The nauplius has only one eye, containing a photo receptor, and uses a pair of antennae as fins for swimming [9].

During development, Artemias gradually grow additional limbs along the elongating trunk. As larvae grow, body length increases from about 0.4 mm to 4 mm, the mean swimming speed increases from 1.8 mm/s to 9.9 mm/s, and frequency of fins beat decreases from 9.5 to 6.7 Hz [10], [11], [12].

Several experiments have been performed to understand Artemia's behavior under several external fields. In fact, without external stimuli, Artemias move individually in random directions. For this reason, the behavior of Artemias under light, electromagnetic and DC fields has been investigated and video recordings have been performed. This step required special care, since the small size and semitransparent orange color of Artemia makes difficult the identification of single individuals in a video or single frame.

Artemia have been hatched in a circular tank with 20 cm diameter and then transferred (with a piped or medicine dropper) in a smaller disk where their motion under different environmental conditions has been observed. To this purpose a digital camera with a 6x optical zoom and 10 Megapixels resolution has been used to record the Artemia trajectories which have been then analysed by image processing techniques. The circular tank is filled of one liter of natural water added with a tea spoon of salt. Then, eggs are added. Finally a light on the tank, necessary for hatching Artemia eggs, has been applied. After 24 to 48 hours the eggs start to hatch.

A smaller number of Artemias are taken from the hatched Artemia population and transferred to a small tank where their motion is observed and recorded. A dark environment is used in order to eliminate the effects of environmental light and to have a black background which increases the contrast of movies and pictures.

From our recordings we can observe that, under uniform light, each Artemia swims independently from the other, taking random directions. From the analysis of such movies, it can be also noticed that under normal distributed light Artemias perform avoid the other individuals, thus performing a simple obstacle avoidance. Examples of motion under uniform light are shown in Fig. 1.

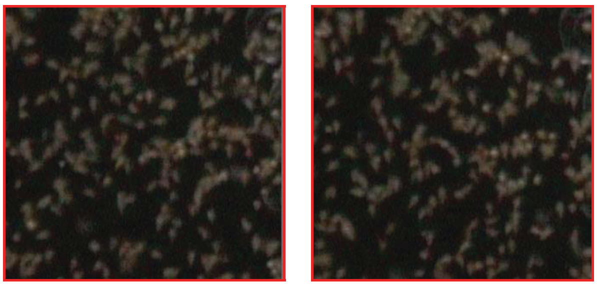

Figure 1. Artemia motion under uniform light.

A second set of experiments has been directed to verify if the motion of Artemia can be controlled by means of some external influences. A spot of light instead of a uniform light source has been used. In this case, Artemias direct towards light, thus following a preferential direction and exhibiting a flocking behavior, as shown in Fig. 2.

It has been also observed that Artemias change their motion direction following the light spot. In more details, two white sources of light, displaced in the two opposite sides of the black box, have been used. In these experiments, first, the left light source is turned on, while the right light source is off, most of Artemias direct to the left light source. At this point, we turn off the left light source and turn on the right light source: Artemias change their motion direction and swim towards the right light source. In order to test Artemia sensitivity to light wavelength, we used four types of light sources (white, blue, green and red LEDs) with the same light power, arranged in the left side of box, and fixed the same type of light sources in right side of box. The results of this experiment, repeated for different light wavelengths, showed that white and blue colors are more attractive for Artemias than green and red colors. This means that Artemias sense more light with short wavelength.

Figure 2. Artemia motion under a spot of light.

Although it is known that Artemia Nauplii only have a photo receptor, we cannot exclude that they are sensitive to other external influences. The effect of some other influences on the Artemia behavior in order to investigate new possibilities for the control of the Artemia motion direction has been then tested. In particular, the following external influences have been taken into account: DC current, electromagnetic field, magnetic field and acoustic signal. In the DC current experiment two plates connected to a 5 V DC source have been used. The Artemia are let swimming under the influence of this current for about 10 minutes with no light: no effects have been noticed. Then, the DC current has been replaced by an electromagnetic field generated by a 100 turn coil, powered with a sinusoidal signal with a frequency of 1-10 kHz and amplitude of 5 V. The duration of this experiment has been again fixed to 10 minutes. Then, the effect of a magnetic field has been tested: a magnetic iron has been tested by leaving the Artemia under this influence for about 10 minutes with no light. Finally, the effects of acoustic signals have been tested by means of a speaker connected to a sinusoidal signal with frequency above 20 kHz, under the same conditions of the other experiments (10 minutes, no light). In all these experiments Artemias don't show any answer to these influences.

III. MODELLING ARTEMIA POPULATION MOTION

In this section, a mathematical model of the motion of the Artemia population is introduced and compared with experimental observations. The model is based on the approach, discussed in [7], which relies on Newton equations derived for each individual of the population. The model is first derived taking into account the case of uniform light and is then extended to the case of spot light source.

As already discussed, in the case of uniform light, Artemias swim in random directions, performing avoidance of the other individuals. In this case, the following Newton equations for each individual can be obtained:

$$m\frac{d\vec{v}_i}{dt} = a\vec{n}_i - \gamma\vec{v}_i + \sum_{i\neq j}\alpha_{ij}\vec{f}_{ij}$$

where m is the Artemia mass, v_i is the velocity of i-th individual ($v_i = |v_i|\exp(\theta_i)$), γ is the resistive coefficient, a is the locomotive force which acts in the heading direction n_i.

The term f_{ij} represents the repulsion force between the i-th and j-th individuals. Breder [13] reported that the interaction force between animals in a given radius can be represented as an intermolecular-like attraction and repulsion force. In our case, this is only a repulsive term which can be modeled as:

$$\vec{f}_{ij} = -c\left[\left(\frac{|\vec{r}_j - \vec{r}_i|}{r_c}\right)^{-2}\right]\left(\frac{\vec{r}_j - \vec{r}_i}{|\vec{r}_j - \vec{r}_i|}\right)$$

where r_c is the optimal distance between neighbors, and c is a parameter that represents the magnitude of interactions.

The repulsion needs not to be isotropic. If the repulsion is based on visual information as in the case of Artemias, the repulsion with individuals moving in front of a given individuals is stronger than those with individuals moving behind it. This is taken into account by the following direction sensitivity factor α_{ij} [8]:

$$\alpha_{ij} = 1 + d\cos(\beta)$$

where β is the angle between the heading vector of i-th individual and a unit vector directed from the i-th individual to the j-th individual and d ($0<d<1$) is a parameter controlling the anisotropy of the sensitivity.

In the case of motion under light spot source, Artemias swim towards a common direction in a flock. The Newton equations for each individual should be modified in order to take into account that two attraction terms have to be included. One attraction term represents attraction towards the light spot, and the second one accounts for group formation while directing towards the light. In the case of fish schools, attraction is directed towards the center of the school [7]. In our case, the attraction direction is determined by the light. Taking into account these considerations, the Newton equations for each individual become:

$$m\frac{d\vec{v}_i}{dt} = a\vec{n}_i - \gamma\vec{v}_i + \sum_{i\neq j}\alpha_{ij}\vec{f}_{ij} + \vec{g}_i$$

The term f_{ij} represents a short-range interaction force between the i-th and the j-th individuals. This term includes repulsion between individuals (to avoid collision) and attraction for group formation, as follows:

$$\vec{f}_{ij} = -c\left[\left(\frac{|\vec{r}_j - \vec{r}_i|}{r_c}\right)^{-3} - \left(\frac{|\vec{r}_j - \vec{r}_i|}{r_c}\right)^{-2}\right]\left(\frac{\vec{r}_j - \vec{r}_i}{|\vec{r}_j - \vec{r}_i|}\right)$$

where the first term is the repulsion force and the second term is the attraction term.

The attractive force to the light spot is indicated as g_i and given by:

$$\vec{g} = C_g * Kv_i * Kr_i * \frac{(r_a - r_i)}{(|r_a - r_i|)}$$

where K_{vi} and K_{ri} are the speed and sensitivity coefficient, respectively, and r_a and r_i are light and individual positions respectively.

IV. CONTROL OF ARTEMIAS MOTION

From the experimental analysis carried out and the theoretical model proposed, it can be derived that Artemias motion can be controlled by using a light source. The idea to perform Artemia motion control is to control the light source position in order to drive Artemias motion. In this Section, a robotic system able to implement this idea is briefly described.

The robot consists of two parts. One is immersed in the water environment where Artemias swim. This part is equipped with a LED light source and magnets. The second part is a mobile wheeled robot equipped with magnets able to attract the first part of the robot. Therefore, the robot part carrying the LED light can be moved by controlling the wheeled part (not immersed in the water environment). Since Artemias are not influenced by magnetic fields, this solution does not affect motion control. The schematic of the robot is shown in Fig. 3.

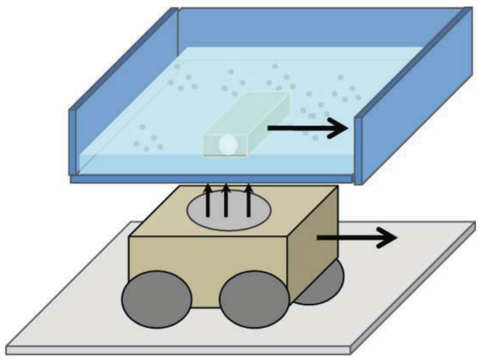

Figure 3. Schematic of the robot used for controlling Artemias motion.

The robot has been implemented by using Atmega162 Microcontroller for robot main board, ZigBee wireless standard for wireless control by PC, two servo motors and fixed three magnetic on this mobile robot to attracted the three iron ball wheels of the mechanical robot inside water. The different experiments performed on Artemias population have confirmed the suitability of the approach. Artemias are able to follow the light source (under different trajectories: linear, circular, zigzag, etc) if the speed of the robot is fixed to suitable values (typical values v=0.3 cm/s). Some frames of one of such experiments referring to a straight line trajectory are reported in Fig. 4.

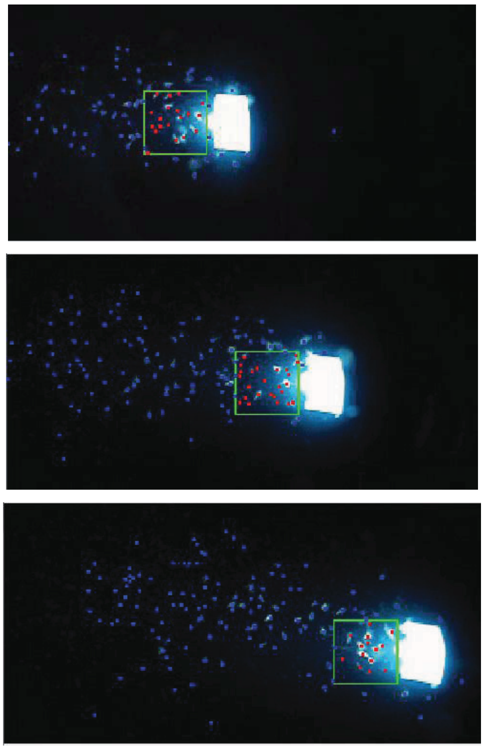

Figure 4. Frames showing motion control of an Artemias population through a robotic system.

V. CONCLUSIONS

In this paper, collective motion of a population of Artemias has been investigated and then controlled. First, a series of experiments devoted to understand their behavior with respect to several external fields has been performed. These experiments showed that it is possible to control the motion direction of an Artemia population, moving as a flock, by using a spot of light. The experiments also showed that Artemias are more attracted by short wavelength and high intensity light. Moreover, a mathematical model reproducing the observed behavior has been derived. The model, based on the derivation of Newton equations for each individual of the population, can explain the mechanisms underlying flock and attraction to the light in the population in terms of attractive and repulsive forces.

Starting from the analysis of the experimental observations and model behavior, a robot system has been conceived to control the Artemias motion. The system is based on the idea of inserting a mobile part in the water driven by an external structure. The interaction between the two parts occur through magnetic force which, according to our experiments on Artemia motion, has been demonstrated to not affect the motion. Thanks to this system, the mobile part can be not equipped with actuating systems which on one hand could affect the Artemias motion and on the other hand could be difficult to be realized in such small dimensions.

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