Synthesis of chaotic space-time structures by swarm of control objects

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Abstract. The problems of constructing chaotic space-time structures by a swarm of control objects of small sizes have been considered. The most methods for movement simulation are developed for the conditions, when the object’s form, movement environment, and control strategies are rather well known. In this paper the chaos organization model is constructed as a model of Craig Reynolds’ swarm movement, into which special fuzzy coefficients are introduced. Varying these coefficients allows influencing the size of the swarm and significantly changing the relative position of the swarm elements. When such structures are created, the errors in predicting the further actions of the swarm increase and the assessment of the swarm behavior by an external observer becomes much more difficult. We have shown that for the case when the group forms a swarm, the size and shape of the swarm are essential for forecasting. The paper shows that the introduction of special coefficients into the well-known algorithm of Craig Reynolds’ swarm movement can provide such rearrangements.

1. Introduction
A swarm is a group of objects in which objects, as a rule, have the same functional roles, and the distances between objects are comparable to their sizes [1]. If we draw an analogy with nature, then the swarm has a dense compact form, it fulfills a single mission. It is not fully known how and by what the natural swarm is controlled, but there are hypotheses that there is a certain small group of “leaders” that determine the swarm behavior; the rest of the elements use the theory of similarity and act by analogy with the behavior of “leaders”, observing certain simple rules. These rules include: a) equalization of speeds, b) “repulsion” to ensure non-collision, and c) “attraction” for the purpose of joint movement.

Let a group of control objects, formed as a swarm, carry out some mission in the opposing environment [2, 3]. Let’s introduce the concept of an external Observer. It is understood as a certain system representing the interests and capabilities of the opposing environment (example: the protection of a territorial object). Using its technical means, the Observer can monitor and predict the behavior of both an individual element of the group and the entire group, and in the event of a threat to it—and actively counteract the group’s performance of a collective mission that is unknown to it.

The ability of the Observer to predict the behavior of a group in the process of solving its assigned tasks, as well as the possibility of its active counteraction, can significantly complicate the performance of a given mission by the swarm.
2. The emergence of irrationality in the swarm behaviour

Let us formulate the following hypothesis: a change in the shape and size of a swarm in the course of a mission can significantly complicate the situational awareness of the Observer in all three of its components—the processes of collecting information, recognizing intentions, and even forecasting. Within the framework of such a strategy, the swarm makes decisions that are “inappropriate” from the point of view of the Observer, which, nevertheless, are planned in advance by the Swarm Creator and are elements of the collective strategy of its behavior.

By our definition, a rational swarm is compact. And if it is moving in a direction that poses a threat to the Observer, then its mission is relatively predictable and its strategies are rational [4–6]. The Observer, assuming the swarm behavior to be rational, can model and predict its state [7, 8]. It fixes the space-time structures of the swarm over a certain period of time (for some applied problems—no more than the first tens of minutes). Further, the Observer can extrapolate its position in space and time, according to the well-known extrapolation formulas in order to counteract the swarm mission by its active actions at a pre-emptive point in space and at the predicted time if there is a threat to the guarded object. Thus, the approach proposed in [9] makes it possible to recognize its current trajectory in real time during several iterations with the help of several recognizer objects comparing changes in the graphical representation of the object’s trajectory.

3. Algorithm for the formation of the swarm behavior irrationality

The swarm behavior irrationality will consist in a change in the shape of the swarm in space and time, possibly with a gradual “disintegration”, that is, the formation of swarms of smaller scale included objects and, possibly, with the transition of the space-time structure from a swarm to an extended swarm.

It is proposed to simulate such rearrangements by introducing special coefficients into the well-known Craig Reynolds’ algorithm. To do this, we introduce fuzzy numbers \( \alpha, \beta, \gamma \in [0,1] \) into the swarm formulas by Craig Reynolds [10], whose membership functions can be directionally changed over a given time interval. Let us call such coefficients the “irrationality coefficients”. The introduction of such coefficients ensures the deceleration or acceleration of the entire swarm movement, the compression or expansion of the swarm in space in terms of its “thickness”, or, conversely, the deviation of the position of each object from the best one in the last iteration is taken into account. Irrationality coefficients can also influence the tendency of each swarm object in order to tend to the best position for the entire swarm.

Figures 1–4 show static illustrations of the manifestations of the swarm irrational behavior in the area of responsibility of the means of observation of the external Observer.

In standard situations, the swarm moves in space, maintaining its overall compactness and shape, close to a ball or ellipsoid with axes slightly different in size (see figure 1). At the moment of predicting an event or detecting that the swarm is controlled by the external Observer, a decision is made to introduce irrationality into the swarm behavior. Depending on the tasks performed by the swarm, due to variations in the irrationality coefficients, various space-time structures of the swarm can be formed: acceleration and deceleration of the swarm movement, fast or slow swarm transition into an elongated line, as vertically with a change in the heights of movement (see figure 2). The most interesting and difficult for the external Observer to predict are the maneuvers of the swarm retraction to a conditional point and the subsequent “scattering” of objects with a change in the swarm density, with a significant scatter of elements with uneven density (see figure 3). It seems that such changes in the structure and shape of the swarm have the strongest effect on recognition of the swarm intent.

In critical cases, if necessary, it is possible to ensure the swarm “disintegration” into two or more swarms of smaller and different sizes. This is achieved by numbering the objects of the swarm and by imparting different irrationality coefficients to the selected numbers of the swarm objects (see figure 4).
The algorithmic language Buzz, a programming language for a self-organizing swarm of unmanned aerial vehicles, has been developed abroad [11]. It already implements procedures for dividing robots into groups, each of which will have its own task. The use of such a language together with the ideas of directed irrationality can be a very effective way of solving collective problems in the face of opposition.

4. Problems and the ways to address them
The study of the possibility of constructing chaotic space-time structures has shown the following issues.

The original swarm in Craig Reynolds’ model is randomly generated. In each implementation, a relatively grouped but different swarm can be observed. In principle, with a relatively small size of the swarm (up to 200–250 objects), it is easy to arrange them in space in the manner necessary for further rebuilding, by setting the appropriate coordinates. Thus, the initial state becomes spatially oriented.
The chaotic structure in the model is not created on purpose, but in fact, by manually selecting the coefficients. The Craig Reynolds’ algorithm fails to achieve targeted chaos. The construction of such a chaotic structure can be ensured by memorizing the type of the resulting chaotic structure and fixing the fuzzy values of the coefficients at which it was obtained. In this case, it is possible to ensure the repeatability of creating a chaotic structure.

If we put the tasks of creating a chaotic structure among the main ones, then it is advisable to initially number all the swarm elements in order to subsequently organize them into corresponding, smaller groups. In this case, for each swarm element, it will be necessary to set a set of coefficients that are common for this group.

5. Conclusion
In practice, there are problems in which, from the point of view of the implementation of a collective mission, the movement of a group of control objects should be purposeful, and, in terms of the external Observer, undefined. The purpose of such space-time constructions is to create an increasing error in predicting the group movement by the external Observer. At the same time, the External Observer perceives the irrational behavior of a group of robots as chaotic, unfocused and makes mistakes when predicting its further actions, which contributes to the implementation of the collective mission.

For the case when the group forms a swarm, the size and shape of the swarm are essential for forecasting. The paper shows that the introduction of special coefficients into the well-known algorithm of Craig Reynolds’ swarm movement can provide such rearrangements.

The irrational behavior of the swarm is most strongly influenced its best point at the previous iteration of the algorithm by the priority for each swarm object. Slightly less influential in creating irrationality is the object’s pursuit of the best point in the entire swarm.

At present, the number of applied tasks requiring the use of a swarm movement is very limited. Perhaps the only actively developing area is the increasingly widespread spectacular swarm formations in the interests of show business. However, the general trend of miniaturization of control objects suggests that the relevance of the issues under consideration for solving other problems, primarily those related to military applications, will increase. Thus, the departure of a part of unmanned aerial vehicles as control objects into the loitering mode significantly changes the structure of the swarm of unmanned aerial vehicles, and its behavior can be perceived as irrational.

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