Applied Soft Computing 25 (2014) 322–335

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Bio-insect and artificial robot interaction using cooperative reinforcement learning

Ji-Hwan Son, Young-Cheol Choi, Hyo-Sung Ahn*

School of Mechatronics, Gwangju Institute of Science and Technology (GIST), 123 Cheomdangwagi-ro, Buk-gu, Gwangju 500-712, Republic of Korea

ARTICLE INFO

Article history:
Received 24 September 2013
Received in revised form 3 September 2014
Accepted 3 September 2014
Available online 16 September 2014

Keywords:
Reinforcement learning
Fuzzy control
Intelligent interaction

ABSTRACT

In this paper, we propose fuzzy logic-based cooperative reinforcement learning for sharing knowledge among autonomous robots. The ultimate goal of this paper is to entice bio-insects towards desired goal areas using artificial robots without any human aid. To achieve this goal, we found an interaction mechanism using a specific odor source and performed simulations and experiments [1]. For efficient learning without human aid, we employ cooperative reinforcement learning in multi-agent domain. Additionally, we design a fuzzy logic-based expertise measurement system to enhance the learning ability. This structure enables the artificial robots to share knowledge while evaluating and measuring the performance of each robot. Through numerous experiments, the performance of the proposed learning algorithms is evaluated.

1. Introduction

In the field of robotics, numerous efforts to establish artificial intelligence have been taken by numerous researchers. However, there has still been no dominant result due to the difficulty of creating artificial intelligence for robots [2,3]. This is especially true in our environment context, which involves complex and unpredictable elements and makes it difficult to apply artificial intelligence in robot applications. The project, called BRIDS (Bio-insect and artificial Robot Intelligence based on Distributed Systems) [1,4], seeks to study interactions between bio-insects and artificial robots to establish a new architectural framework for improving the intelligence of robots. In this project, we use living bio-insects which have their own intelligence to survive in nature. Because of their own intelligence, behavior of the bio-insect also involves complex and unpredictable elements. Therefore, studying an interaction between a living insect from nature and artificial robot will provide an idea of how to enhance the intelligence of robots. In this paper, as a specific task for the interaction between bio-insects and artificial robots, we would like to entice bio-insects towards desired goal areas using artificial robots without any human aid. Thus, the potential contribution of this research lies in the field of robot intelligence; it establishes a new learning framework for an intelligent robot based on cooperative reinforcement learning, which constitutes a type of coordination for a community composed of bio-insects and artificial robots. The research on bio-insect and artificial robot interaction will provide a fundamental theoretical framework for human and robot interactions.

The main focus of our early results [1] was on how to address the uncertain and complex behavior of a bio-insect under a constructed framework for robot intelligence. The first goal was to find available interaction mechanisms between a bio-insect and an artificial robot. Contrary to our expectation, the bio-insect did not react to light, vibration, or movement of the robot. From various trials and errors, we eventually found an interaction mechanism using a specific odor source from the bio-insect's habitat. Additionally, to develop a framework, we made an artificial robot that can spread the specific odor source towards a bio-insect. Then, to evaluate interaction ability of the mechanism, we conducted experiments using the artificial robot, which was manually controlled by a human operator. In the experiment, by the human operator the artificial robot was considered that the robot has enough knowledge to entice the bio-insect towards desired point, and the experiment result showed that the artificial robot can entice the bio-insect. The second goal was to entice a bio-insect towards the desired goal area using an artificial robot without human aid. To achieve the second goal, we conducted two types of experiments to entice a bio-insect towards the desired goal using an artificial robot without human aid. The first type of experiment was conducted using fuzzy logic based reinforcement learning and second type of experiment used simple regular reward based reinforcement learning. From the experimental results, we found that fuzzy logic based reinforcement learning showed more efficient results.

* Corresponding author. Tel.: +82 62 715 2398.
E-mail addresses: jihwan@gist.ac.kr (J.-H. Son), cyc@gist.ac.kr (Y.-C. Choi), hyosung@gist.ac.kr (H.-S. Ahn).

http://dx.doi.org/10.1016/j.asoc.2014.09.002
1568-4946/

However, it took a huge amount of learning time for the robot to acquire the necessary knowledge though it eventually obtained the knowledge by the learning process. Furthermore, due to the complex and unpredictable behaviors of a bio-insect, the single reinforcement learning process was insufficient to enable a reliable and efficient learning. Thus, for an efficient learning (i.e., to improve the success rate in a faster learning time), we decided to use a cooperative learning mechanism in multi-agent domain. In Ref. [4], we conducted experiments using two artificial robots. In the experiments, we used fuzzy logic based expertise measurement system for sharing knowledge and obtained successful results. This paper is an extended version of Ref. [4]. In this extended version, we have generalized a fuzzy logic based expertise measurement system and presented more detailed explanation of the system. In the previous version, the effect of sharing knowledge might not be clear and the experiment result appeared quite optimal at the beginning. Therefore, we have newly conducted two types of experiments: Experiment A – without sharing knowledge case and Experiment B – sharing knowledge case. In the Experiment A, individual agents 1 and 2 have performed to entice a bio-insect together without sharing knowledge. The Experiment B has focused on sharing knowledge between the two artificial robots to entice a bio-insect together. Also, the number of action points has been increased and the artificial robots have needed more trials-and-errors to find out suitable angle direction and optimal distance range to entice the bio-insect. After conducting experiments, we have obtained newly experimental results.

Note that we use the term "cooperative learning" to represent a learning by sharing data among multiple autonomous robots. When a robot is faced with given commands for which the robot lacks a sufficient knowledge base and is required to act alone, the robot may not be successful in implementing the commands. Or the robot takes a long time to complete the task. However, if there are several other robots and each of the robots possesses their own specialized knowledge about the task, then the given commands can be more readily completed by mutual cooperation. Moreover, when the robots learn knowledge from trials and errors, some of the robots may have more specialized knowledge than the others, as seen in human society. If the robots have the ability to share knowledge, then the performance of the robots would be enhanced. For these reasons, cooperative learning has recently received a lot of attention due to the various benefits it provides.

In a relationship between a predator and prey, a predator needs to learn hunting skills to survive in nature. By trials-and-errors, the predator will obtain useful knowledge to capture prey, and success rate of hunting will be increased as shown in Refs. [5,6]. However, due to complex and unpredictable elements in nature, the predator cannot be always successful in hunting prey even though the predator has enough knowledge in hunting. For example, weather conditions, species of prey, and physical elements of the predator and prey, etc. are different whenever the predator hunts a prey. The elements affect the success rate of hunting of the predator [7,8] and make it difficult to capture a prey. At least, the predator can learn available hunting skills by its own trial and error process, and it can survive in nature.

From a behavioral point of view, the basic concept of reinforcement learning is similar to learning mechanism of animal using positive and negative reward through trial and error process. This process is similar to the relation between an artificial robot and a bio-insect. The artificial robot needs to find out how to entice the bio-insect by trial and error process. As a predator cannot fully capture a prey due to complex and unpredictable environment, the artificial robot cannot entice the bio-insect at all times because of complex and unpredictable elements of the bio-insect. At least, the artificial robot learns to have useful knowledge to entice the bio-insect. Because of these similarities, therefore, we consider that this approach is a fully adaptable and useful solution. In addition, due to the merit of this process, the reinforcement learning has a lot of attention and has been applied to various fields. Using the reinforcement learning, they have controlled helicopter flight [9], movement of elevator [10], humanoid robots [11], soccer robot [12], and traffic signal control [13]. Also, they have applied into spoken dialogue system [14], packet routing [15], production scheduling [16], traveling salesman problem [17], and resource allocation [18].

As a basic step, we have focused on using a living bio-insect, called stag beetle, as a target in interaction with robots. Based on interaction mechanism we found, we attempt to control movement of the bio-insect without any human aid. To achieve this goal, the robots need to learn how to control behavior of the bio-insect. The problem is that a bio-insect contains own low level intelligence composed of ganglia to survive in nature. Therefore, behavior of the bio-insect also contains complex and unpredictable elements, and the elements make it hard to control the bio-insect. In our previous experimental results using a robot controlled manually by human operator [1], we achieved only 80% success rate. This result implies that reactions of the bio-insect are not always equal to what we expected, and the amount of reaction is different at every trial. In these conditions, the robots need to learn precise knowledge to entice the bio-insect towards desired goal area. If we know what the bio-insect thinks of future movement in current situation, then the robots may entice the bio-insect in an efficient way. However, the robots have some clues, which only were acquired from behavioral reaction of the bio-insect. To overcome these difficulties, we applied reinforcement learning and fuzzy logic in this paper.

To apply the reinforcement learning into real robot, a generation of a precise reward is a crucial issue for an accurate learning. To deal with this complexity of the environment, we found that the fuzzy logic could be one of the profitable approaches for generating a reward. We expect that this process will make robots do more active learning than a sole reinforcement learning by adequately generating a reward from behavioral reactions after interacting with the bio-insect. Therefore, we adopt the fuzzy logic into our learning structure. Also, when sharing knowledge for a cooperative learning, classifying and finding experts in each specific field among agents also contain complex elements. Therefore, we also use fuzzy logic to measure performance of each robots. Then, based on the developed fuzzy rules, the system calculates performance of each robot in each specific fields.

This paper is organized as follows. In Section 2, we briefly introduce a project entitled BRIDS (Bio-insect and artificial Robot Interaction based on Distributed Systems). In this section, we also present the main purpose and goal of the research. In Section 3, we present the fuzzy logic-based cooperative reinforcement learning using an expertise measurement system. Using the aforementioned structure, we present experimental setup and results in Section 4. In Section 5, we present a discussion of our experimental results. Finally, Section 6 provides a conclusion of this paper.

2. Bio-insect and artificial Robot Interaction based on Distributed Systems

2.1. Motivation and goal of the BRIDS

The BRIDS seeks to study bio-insects and artificial robots interaction to establish a new architectural framework for improving the intelligence of mobile robots. One of the main research goals is to drive or entice a bio-insect through the coordination of a group of mobile robots towards a desired point. The research includes the establishment of hardware/software for the bio-insect and artificial robot interaction and the synthesis of distributed sensing,