Chapter 2
Probabilistic Control and Swarm Dynamics in Mobile Robots and Ants

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ABSTRACT

The chapter considers the method of probabilistic control of mobile robots navigating in random environments and mimicking the foraging activity of ants, which is widely accepted as optimal with respect to the environmental conditions. The control is based on the Tsetlin automaton, which is a minimal automaton demonstrating an expedient behavior in random environments. The suggested automaton implements probability-based aggregators, which form a complete algebraic system and support an activity of the automaton over non-Boolean variables. The considered mobile agents are based on the Braitenberg vehicles equipped with four types of sensors, which mimic the basic sensing abilities of ants: short- and long-distance sensing of environmental states, sensing of neighboring agents, and sensing the pheromone traces. Numerical simulations demonstrate that the foraging behavior of the suggested mobile agents, running both individually and in groups, is statistically indistinguishable from the foraging behavior of real ants observed in laboratory experiments.

INTRODUCTION

Starting with pioneering works in cybernetics, the progress in computational machinery and robotic research is strongly inspired by the studies of intellectual behavior of living organisms. A basic role in such studies plays the activity of individual ants and dynamics of their colonies, providing the main source of insights for developing multi-agent robotic and intellectual systems (McFarland & Bösser, 1993; Weiss, 1999). On the other hand, the progress in optimization methods

DOI: 10.4018/978-1-4666-6078-6.ch002

and mathematical modeling of collective behavior of automata leads to better understanding of animal and insect activity (Cole & Cheshire, 1996; Couzin, *et al*., 2005; Gordon, 2010; Sumpter, 2010; Viswanathan, et al., 2011).

Similarly to living organisms, the teleological activity of autonomous mobile robots in a random environment implies certain decision-making processes which allow fulfilling the mission in spite of environmental uncertainty and the changes in the environment as a result of the robot's actions. To specify such behavior, usually the robots' controllers are considered as probabilistic automata with certain learning abilities and are studied following two general approaches. According to the classical approach, the consideration begins with a definite mission of the mobile robot, for which an optimal or near-optimal control and navigation are specified. The second approach, in contrast, starts with certain observed activity of a living organism, mainly – its motion in the environment, and based on that a mobile robot is developed, equipped with the appropriate sensors and controllers, such that it mimics the living organism activity. Below, we follow the second approach and consider biologically-inspired navigation of mobile robots controlled by probabilistic automata.

The studies in modeling of living organisms activity using probabilistic automata can be traced back to the rise of cybernetics in the end of 1940s, and in 1960s the basic automata models of the simplest forms of biological behavior were developed (Fu, 1967; Fu & Li, 1969; Tsetlin, 1963). Additionally, during that time the studies of interacting automata have been started (Chandrasekaran & Chen 1969; Tsetlin, 1973) that led to the considerations of the dynamics of automata colonies (Verbeeck & Nowé 2002) following the same approach that is used in the studies of the colonies of ants. In the last few decades, the studies aimed to develop the artificial agents that mimic the intellectual abilities of living organisms, such as insects and even mammals, are combined in the unified framework known as ANIMAT (ANImal-autoMAT). Starting from 1991, the results obtained in this direction are presented in the proceedings of the annual conference "From Animals to Animats" (1991-2012).

The presented work is motivated at most by the problem of search and foraging by mobile robots and their societies (Chernikhovsky, *et al.*, 2012; Israel, *et. al.*, 2012; Kagan, *et al.*, 2010, 2012). This task requires the definition a method of the most effective way of searching for the hidden object if only its location probabilities are known. In the framework of the studies of mobile agents, such problem requires a definition of the agents' behavior, who perform the search task. Starting from its original formulation in 1942, this problem was considered using different optimization techniques. A detailed review of the methods and results obtained in optimal control of mobile robots in the tasks of search and evasion is presented in the paper by Chung, Hollinger & Isler (2011); additional information on probabilistic search and optimization techniques can be found in the book by Kagan & Ben-Gal (2013b). However, because of the high complexity of the search problem and wide variety of conditions, which have to be taken into account, in most cases an optimal search planning is far from a successful solution, and the Stone remark that "planning of search is not solely an analytical exercise. Since subjective judgments are crucial to good search planning, search will always, to some degree, be an art" (Stone, 1983, p. 231), is still relevant.

To overcome these difficulties, we considered the methods of navigation and control of mobile robots in order to obtain a resulting motion of the robots such that it is as much as possible the same as the foraging activity of the ants. Such a consideration follows general assumption that animals, and particularly insects, forage optimally, that is "the evolution and adaptation of foraging behavior should approximately reach completion with individuals foraging in ways close to (i.e.