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Experimental investigation on coverage performance of a chaotic autonomous mobile robot

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HIGHLIGHTS

- We experimentally investigate the coverage performance of a chaotic autonomous mobile robot.
- The robot's motion controller is based on a microcontroller for realizing a chaotic random bit generator.
- The chaotic system in the proposed generator is a discrete chaotic system, the Logistic map.
- An ultrasonic distance sensor for providing short-range distances to obstacles or boundaries has been used.
- The robot scans fast with unpredictable way the chosen workspace.

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ABSTRACT

In many autonomous mobile robotic missions the complete and fast coverage of the workspace, scanned by an unpredictable trajectory, plays a crucial role. To satisfy these special demands in the design of an autonomous mobile robot, a motion controller, based on the dynamical behavior of a known discrete chaotic system, the Logistic map, is presented in this paper. The proposed method is based on a microcontroller for realizing a chaotic random bit generator and converting the produced chaotic bit sequence, to the robot's trajectory of motion. The experimental results confirm that this approach, with an appropriate sensor for obstacle avoidance, can obtain very satisfactory results in regard to the fast scanning of the robot's workspace with unpredictable way.

1. Introduction

In the last decades mobile robotics and especially the design of autonomous mobile robots has become a very promising research field because many interesting applications in difficult or dangerous tasks for humans have been found. In general, an autonomous mobile robot can perform a task without continuous human supervision. Terrain exploration for searching for explosives [1], complete coverage of a terrain (like floor-cleaning robots) [2,3], transportation [4], search and rescue of human victims on disaster places [5], map buildings [6] and surveillance of terrains [7–10] are some of the civil or military tasks, where autonomous mobile robots can be very useful.

Fundamental issues in the design and development of autonomous mobile robots span the locomotion, sensing, localization and navigation. However, the most challenging issue is the choice of the navigation strategy. A navigation strategy can be defined as the set of various techniques that allow a mobile robot to autonomously decide where to move in the workspace in order to accomplish a given task. Also, navigation strategies have a remarkable influence over the performance of the task execution and significant contribution in building the robot's autonomy. Many interesting navigation techniques depending on the application have been proposed so far, but the issue continues to preoccupy the scientific community.

So, covering all the possible classes of problems involving navigation strategies, such as the exploration of an initially unknown workspace in order to discover explosives or the patrolling of a known environment, the key-point is the robot's motion planning for the complete and fast workspace scanning. For accomplishing these requirements, a mobile robot which is capable of crossing

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every region, covering systematically the entire workspace, should be designed. An obvious solution is a systematic scan by using the parallel straight trajectories. Nevertheless, this approach could be easily understood by an intruder in the case of a patrolling mission. Therefore, the unpredictability of the mobile robot's trajectory is also a crucial factor for the success of such autonomous robot's tasks.

In 2001, Nakamura and Sekiguchi proposed a strategy to solve the above mentioned problem based on chaotic systems [11]. In that work, the chaotic behavior of the Arnold dynamical system is imparted to the mobile robot's motion control. Since then a great number of relative research works in the field of autonomous mobile robots have been presented, because the chaotic motion guarantees the scanning of the whole workspace without a terrain map or motion plan. Lorenz dynamical system [12,13], Standard or Taylor–Chirikov map [14–16], Chua circuit [1,17], and double-scroll systems [18–20] are some of the chaotic systems which have been used for this purpose.

Until now the great majority of the similar works on the specific subject have presented only numerical simulations of the autonomous robots' motion. In this work, a new navigation strategy by designing a controller, which ensures a chaotic motion to an autonomous mobile robot, has been experimentally investigated. This new technique is implemented by using a well-known micro-controller for solving the discrete chaotic dynamical system, the Logistic map, and realizing a chaotic true random bit generator. The proposed generator produces an unpredictable trajectory by imparting the chaotic behavior of the system to the two independent active wheels of the mobile robot. As a consequence, the autonomous mobile robot with a sensor for obstacle avoidance covers the whole workspace with unpredictable way.

This paper is organized as follows. In Section 2 the features of chaotic systems and especially the Logistic map, which is the key-point in this work, are presented. The adopted chaotic robot's motion controller and the proposed model for the autonomous mobile robot are described in Sections 3 and 4 respectively. The experimental results and their analysis in two different obstacle avoidance approaches are presented in Section 5. Finally, Section 6 includes the conclusion remarks of this work.

2. The logistic map

Since the discovery of deterministic chaos in the mid 1960s, the field of nonlinear dynamical systems has attracted the attention of researchers worldwide. Such phenomenon which is characterized by the system's high sensitivity on initial conditions [21] has been studied deeply in several physical, biological, sociological and engineering fields [22–25]. With the term sensitivity on initial conditions, it is meant that a small variation on a system's initial conditions will produce a totally different chaotic behavior.

Also, it is known that the most important aspects of chaotic behavior should appear in systems of lowest dimension and especially in discrete-time dynamical systems. Discrete-time dynamical systems are a particular type of nonlinear dynamical systems generally described as an iterative map $f : R^n \to R^n$ by the state equation:

$$x_{k+1} = f(x_k), \quad k = 0, 1, 2, \ldots \tag{1}$$

where n is the dimensionality of the state-space, k denotes the discrete time, $x_k \in R^n$ is the state of the system at time k, while x_{k+1} denotes the next state.

The Logistic map, which is described by the following equation:

$$x_{n+1} = r \cdot x_n \cdot (1 - x_n), \quad 0 \le x \le 1 \tag{2}$$

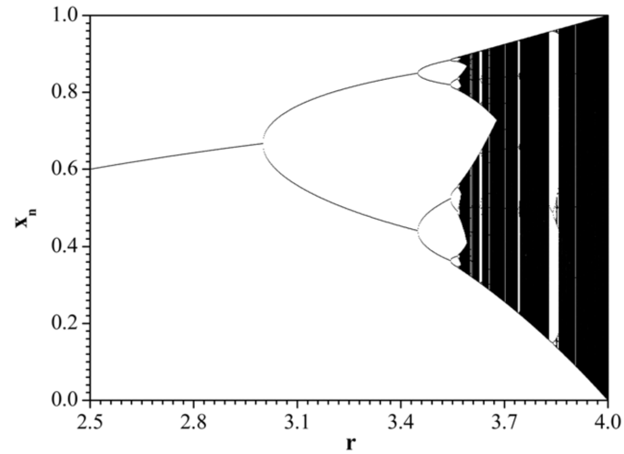

Fig. 1. The bifurcation diagram of x_n vs. parameter r for the Logistic map of Eq. (2).

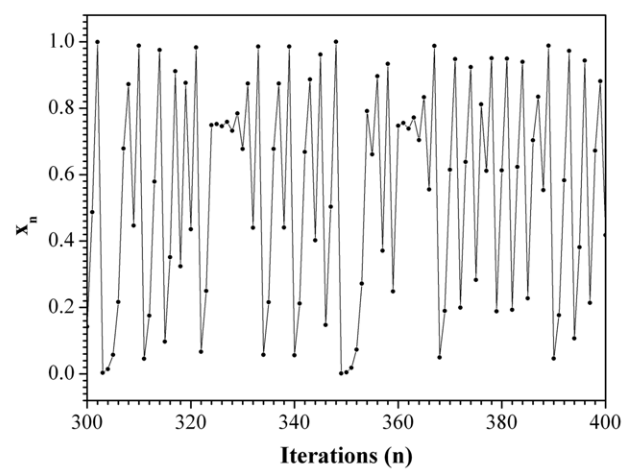

Fig. 2. Variable x vs. n, for $r = 3.999$ and $x_0 = 0.5$.

is one of the most studied, one-dimensional, discrete chaotic maps because of its simplicity. This iterative map has been used in a variety of applications such as a simple idealized ecological model [26] and a pseudo-random number generator [27–33], partly because it had a known algebraic distribution so that the iterated values could be transformed to a uniform distribution. In the next section a different random number generator based on the Logistic map, as a robot's motion controller, will be presented.

In more details, the parameter r in Eq. (2) varies in the interval [0,4]. In Fig. 1 the so-called "Bifurcation diagram" of the Logistic map is shown. This diagram is a very common perspective in nonlinear dynamics, being in this case a plot of the steady-state behavior of Eq. (2) with respect to the bifurcation parameter r. The rich dynamical behavior in the region ($3 \le r \le 4$), which is mainly characterized by the very interesting phenomenon of period-doubling route from periodic to chaotic behavior, is illustrated in this bifurcation diagram.

As it is shown, for $r > 3.5699\ldots$ the Logistic map shows a strange complex behavior (the so-called chaotic behavior) where the map function never repeats its history. This is evident from Fig. 2 where no periodicity arises, for $r = 3.999$ and $x_0 = 0.5$.

Finally, in Fig. 3 the well-known Lyapunov exponent:

$$\lambda = \lim_{n\to\infty} \sum_{i=1}^{n} \ln \left| f'(x_i) \right| \tag{3}$$