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A hybrid evolutionary algorithm for recurrent neural network control of a three-dimensional tower crane

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ABSTRACT

This paper is concerned with the control of an underactuated three-dimensional tower crane system using a recurrent neural network (RNN) which is evolved by an evolutionary algorithm. In order to improve the performance in evolving the RNN, a hybrid evolutionary algorithm (HEA) which utilizes the operators of a constricted particle swarm optimization (PSO) and a binary-coded genetic algorithm (GA) is proposed. Simulation results show that the proposed HEA has superior performance in a comparison with the canonical algorithms and that the control system works effectively.

1. Introduction

Crane systems are widely used in transportation and construction [1]. They are used to move a load from an initial point to a desired point and, at the same time, the load swing needs be suppressed. This task is usually performed by a skillful operator. Nevertheless, control of cranes has attracted much research [1–5], motivated by the fact that automated cranes can reduce the cycle time for suppressing the load swing with accuracy. The potentials of automated cranes are especially well suited when they are mounted in fixed locations repeating almost the same trajectories, like tower cranes in construction. Crane systems usually exhibit underactuated behavior [2,3]. Underactuated systems, which are characterized by the fact that they process fewer actuators than degrees of freedom, have been the subject of much study during the last decades due to its pervasive applications. Many real-world mechanical systems are examples of such systems, where underactuated behavior can even be utilized intentionally [6] in order to reduce the cost, complexity, size and weight by reducing the number of required actuators and related designs. Such systems generate interesting but difficult control problems as they usually exhibit complex dynamics and nonholonomic behavior. Following the potential trend of applying NNs in control systems design [7–9], this study considers the control of a three-dimensional rotary tower crane, which is a five degree-of-freedom model with underactuated nature, by using a recurrent neural network (RNN). As to be shown, the use of RNN-based control system provide convenience to deal with the problem while considering constraints and damping coefficients of the system, which are not always considered adequately in the literature.

Aside from several advantages of NNs, such as good nonlinear processing ability and robustness with inherently parallel architecture, RNNs have interesting properties with great potential and they have shown superiority to feedforward neural networks (FNNs) [10,11]. Although FNNs have been very popular, with only feedforward connections, they are static networks and lack dynamic memory since the response of such networks depends only on current inputs [10]. They are thus unable to represent dynamic mappings without external feedback [11]. In contrast, RNNs have several important capabilities, including attractor dynamics and internal memory. Since a recurrent neuron already has an internal feedback loop, it captures the dynamic response of a system without external feedback through tapped delays [11], RNNs are thus dynamic mappings and are more appropriate than FNNs when applied to dynamical systems. However, despite important capabilities, RNNs are much less popular than FNNs because it is hard to develop a convenient learning algorithm as well as classic gradient-based algorithms, such as backpropagation [12,13], are apparently insufficient/limited [14]. As NNs training can be considered as an optimization problem which apparently contains several local optimum, it should thus be more suitable to utilize global optimization techniques. In order to overcome the problems of RNNs training, as stochastic optimization techniques become available and effective, the last two decades have shown an increasing amount of interest in applying evolutionary algorithms (EAs) to construct RNNs (e.g., see [14,15]). In this paper, attention is paid to the use of an EA as an optimization algorithm to construct an RNN-based controller for the crane.

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Notations

φ	rotation angle of bridge
s	trolley position
ℓ	rope length
θ_1	out-of-plane swing angle
θ_2	in-plane swing angle
M_b	torque actuating tower
F	force actuating trolley
M_w	winch torque
J_b	moment of inertia of jib
J_w	moment of inertia of winch
m_t	mass of trolley
m	mass of load
D_φ	damping coefficient (tower)
D_s	damping coefficient (girder)
D_α	damping coefficient (winch)
r_w	winch radius
g	acceleration of gravity

EAs have been emerging as a growing field of study and applied pervasively in various areas, particularly in control engineering [16–18]. Among the EA-family, genetic algorithms (GAs) [18–21] and particle swarm optimization (PSO) [22–26] seem to be most well-known, and in fact they have shown good performance in NNs optimization [14,19,22,23].

Although it is considered to be a newly developed tool, PSO has appeared to be a simple but fast algorithm with only a few parameters [22–26]. However, it has difficulties in balancing between *exploration* and *exploitation* [25], since PSO seems to be easily “trapped” into a better solution previously found, which could possibly be a local optima. In contrast, and with a long history, GAs have emerged to be one of the most successful in the EA family. As they contain several operators and tunable parameters, it is intuitively easier to control the balance between *exploration* and *exploitation* in GAs.

Although the competences of EAs have been shown to be superior over those of conventional methods, an experienced combination of operations (either fully or partially) from different approaches may provide an even more efficient performance. In fact, the hybridizations of EAs have been the focus of much research recently, and one of the popular and interesting frameworks are the hybrids of GAs and PSO which are capable of handling several real-world problems [27–31]. For example, an interesting work in [28] presents a hybrid of PSO and GA with use of three fuzzy systems: a main fuzzy system is for decision making and the other two fuzzy systems are used to tune the parameters of PSO and GA. In [29], while the lower-half is eliminated, the top-half of the best-performing individuals is considered as elites and they are first enhanced by PSO before applying GA operators. In [30], a hybrid between GA and PSO is introduced where the population is randomly divided into two parts to be evolved with the two methods and then combined in the updated population, which is then again divided randomly into two parts for the next run. To control the percentage of the population developed by GA, a hybridization coefficient with a self-adaptive strategy is employed. In [31] the upper-haft of the best individuals is instead processed by a real-coded GA to create the same amount of new individuals which are then used to adjust the remaining particles by PSO.

Since it is desirable to have an efficient algorithm that can provide a good solution with a small population and within a small number of generation/iteration, in this article a hybrid of a constricted PSO and a binary-coded GA, called a hybrid evolutionary algorithm (HEA), is proposed. In order to develop the HEA, genetic operators of the GA (recombination and mutation) are embedded into the PSO to generate offspring with a fitness-based selection of parents, and an elimination of the inferior individuals is applied to maintain a constant population. While several hybrid EAs have involved the problems of mathematical models and functions optimizations (e.g. [27–29,31]), our focus is to apply the HEA to construct an RNN control of a complex underactuated mechanical system.

The rest of this article is organized as follows. Section 2 introduces a rotary tower crane system and its dynamics. A control system using RNN and EA is also presented. In Section 3, brief backgrounds on the PSO and GA used to construct the HEA are first provided. The proposed hybrid algorithm based on the PSO and GA is then introduced. Simulations are demonstrated in Section 4, where the performance of the proposed method is investigated and compared with those of the original PSO and GA. Control simulations are also shown. Section 5 is a discussion of the results and Section 6 is the conclusion of the study.

2. Three-dimensional tower crane system and control

2.1. Three-dimensional tower crane system

This paper considers a rotary tower crane as shown in Fig. 1. This is a concrete model that has been studied by W. Blajer et al. [2,3],

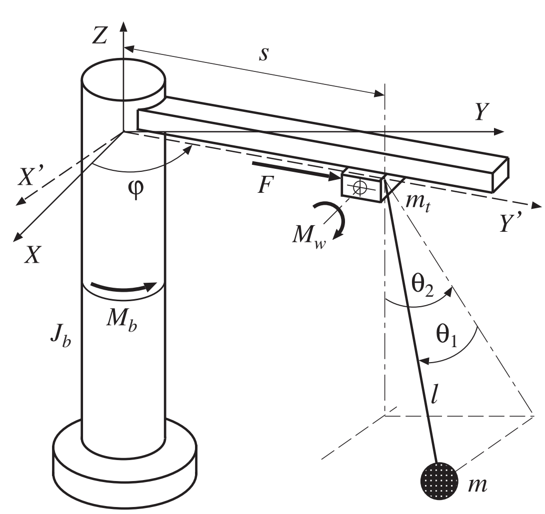

Fig. 1. Tower crane model.