Multi-robot Box-Pushing Using Differential Evolution Algorithm for Multiobjective Optimization

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Abstract. The paper provides a new approach to multi-robot box pushing using a proposed Differential evolution for multiobjective optimization (DEMO) algorithm. The proposed scheme determines time-, energy- and friction sensitive-optimal solution to the box-pushing problem. The performance of the developed DEMO algorithm is compared to NSGA-II in connection with the given problem and the experimental results reveal that the DEMO outperforms NSGA-II in all the experimental set-ups.

Keywords: multi-robot box pushing, friction compensation, differential evolution for multiobjective optimization.

1 Introduction

Optimization of multi-objective functions is essential to many engineering problems. The box pushing problem, dealt with in this paper, is related to the well known “Piano Mover’s Problem”: given an arbitrary rigid polyhedral environment, determine a continuous collision-free trajectory of motion of the object from a source configuration to a desired destination configuration.

The box-pushing problem represents a challenging domain for the study of object manipulation in a multi-robot environment. Since 1990’s researchers took active interest in formulating and solving the box-pushing problem by different techniques. Some of the well known works in this regard include adaptive action selection by the robots without communication [7], mutual cooperation by intension inference [8], cooperative conveyance by velocity adaptation of robots [9], and role of perceptual cues in multi-robot box-pushing [6].

One of the most studied strategies is the well-known “Pusher-Watcher” approach [13, 14]: A robot observes (watcher) the movement of the object and

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control the operations of the team (pushers) that manipulate the box. Recent multi-robot strategies make use of the model known as “swarm intelligence”. Li [15] experiments using communities of homogenous robots. These self-organized systems are based on decentralized and collective behaviors. Another recent strategy is the reinforcement learning. Wang [16] implements a variant including a mechanism of decision based on a Markov process known as “Q-Learning”. The main concern about this technique is related to the storage capacities and high demand of process capabilities. Gene [17] and Lengegyel [18] model the environment by the construction of a configuration space (C-space) and both use the conventional wave front algorithm to compute the trajectories of the box.

In the proposed work, two similar robots have to locally plan the trajectory of motion of the box in a complex terrain, where the robot’s workspace has different frictional coefficients in different regions. In [2], it has been attempted to satisfy multiple objectives concerning minimization of both time and energy required in local trajectory planning of the robots by NSGA-II.

The work proposed in this paper is different by two counts. First, we consider the frictional forces offered by the contact surface to the box. The forces applied by robots must be sufficient to counteract this frictional force. Second, the box-pushing problem has been solved by Differential evolution for multiobjective optimization (DEMO), pioneered by Robic and Filipi [1] as a state-of-the-art literature survey indicates that DE has already proved itself as a promising candidate in the field of evolutionary multi-objective optimization (EMO) [10, 11, 12].

The justification of the use of DEMO in the proposed problem are point wise indicated below: 1) better solution quality 2) efficiently achieving the two goals of multiobjective optimization, i.e., the convergence to the true Pareto front and uniform spread of individuals along the front. It has also been verified in the paper that DEMO has outperformed NSGA-II in trajectory planning of the robots in all the different types of workspace. It is also compared with Multiobjective optimization using differential evolution (MODE) - based simulation and it has been proved that DEMO is better than MODE.

The remaining paper has been organized into sections as follows: In Section-2, a formulation of the problem is presented. In Section-3, a pseudo-code for solving the optimization problem using DEMO is provided and in Section-4, computer simulation for the problem has been laid down for comparison of results using DEMO and NSGA-II.

2 Formulation of the Problem

Suppose two robots R_1 and R_2 are applying forces perpendicularly at points E(x_e, y_e) and F(x_f, y_f) on the front edge BC of the box (Fig. 1). Let O (x_c, y_c) be the centre of gravity of the box . After being rotated by an angle α around the point $I(x_I, y_I)$ due to the forces applied by robots $R_1(F_{1r})$ and $R_2(F_{2r})$ the corresponding new co-ordinates of O, E and F become

$$\left.\begin{aligned} x_{inew} &= x_I(1-\cos\alpha) + x_i\cos\alpha - \sin\alpha\,(y_i - y_I) \\ y_{inew} &= y_I(1-\cos\alpha) + y_i\cos\alpha - \sin\alpha\,(x_i - x_I) \end{aligned}\right\} \text{ where, } i \in P = \{o, e, f\}. \quad (1)$$