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Application of evolutionary algorithms for optimum layout of Truss-Z linkage in an environment with obstacles

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ABSTRACT

Truss-Z (TZ) is a concept of a modular system for creating free-form links and ramp networks. It is intended as a universal transportation system for cyclists and pedestrians, especially ones with strollers or carts, and in particular – by persons on wheelchairs, the elders, etc. In other words, TZ is for people who have difficulties using regular stairs or escalators. With only two types of modules, TZ can be designed for nearly any situation and therefore is particularity suited for retrofitting to improve the mobility, comfort and safety of the users. This paper presents an application of evolution strategy (ES) and genetic algorithm (GA) for optimization of the planar layout of a TZ linkage connecting two terminals in a given environment. The elements of the environment, called obstacles, constrain the possible locations of the TZ modules. Criteria of this multi-objective optimization are: the number of modules to be the smallest, which can be regarded as quantitative economical optimization, and the condition that none of the modules collides with any other objects, which can be regarded as qualitative satisfaction of the geometrical constraints. Since TZ is modular, the optimization of its layout is discrete and therefore has combinatorial characteristic. Encoding of a planar TZ path, selection method, objective (cost) function and genetic operations are introduced. A number of trials have been performed; the results generated by ES and GA are compared and evaluated against backtracking-based algorithm and random search. The convergence of solutions is discussed and interpreted. A visualization of a realistic implementation of the best solution is presented. Further evaluation of the method on three other representative layouts is presented and the results are briefly discussed.

1. Introduction

Truss-Z (TZ) is a modular truss system which can 'organically' adapt to almost any environment and was developed as a universal and affordable construction system for pedestrian walkways [1].

- *Universality*: a single branch of TZ can link virtually any two terminals in space. The system also supports multiple branching, closed loops and spirals.
- *Affordability*: the system is modular, and each branch of the truss is composed of only units, which are mirror reflections of each other. The unit modules are to be prefabricated and assembled on-site, preferably without the necessity for heavy equipment, or can be made on-site using templates and locally available materials.

The same concept can be adjusted in scale and shape for different purposes such as supporting cycle paths or other transportation tasks, and ventilation ducts. It is the first structural system which gives almost limitless geometrical possibilities for creating 3D paths and at the same time is modular. For discussion on free-form vs. modularity see [1]. Unlike other available modular systems, where simple forms result from assembly of simple elements, in TZ, both simple and complex forms are constructed from four variations of a single basic unit which is not overly simplified, as shown in Fig. 1.

The basic module is named according to the 'right-hand grip rule': R, for 'right', since it 'turns left and goes up'. Accordingly, the mirror reflection of R is called L, for 'left'. Each of them, by rotation about the vertical axis can be installed in two different ways, called R2 and L2, which are also mirror reflections of each other. Therefore there are four possible ways of connecting two consecutive modules. Some elementary examples of their spatial configurations are shown in Fig. 2.

In this paper, however, the problem is reduced to the projection on the 2D plane. A single trapezoid, called 1, which corresponds to units R and L2, and its rotation, called 0, which corresponds to L and R2, allow creating a path of virtually any trajectory as shown in Fig. 3.

The example in Fig. 3(1) is a straight path built by of alternating 1s and 0s: 10101010101010101010101; in Fig. 3(2): 10101010100 10101010101; in Fig. 3(3): 111111111111; and Fig. 3(4): 110100001001111110010001100101001000000100110011100110

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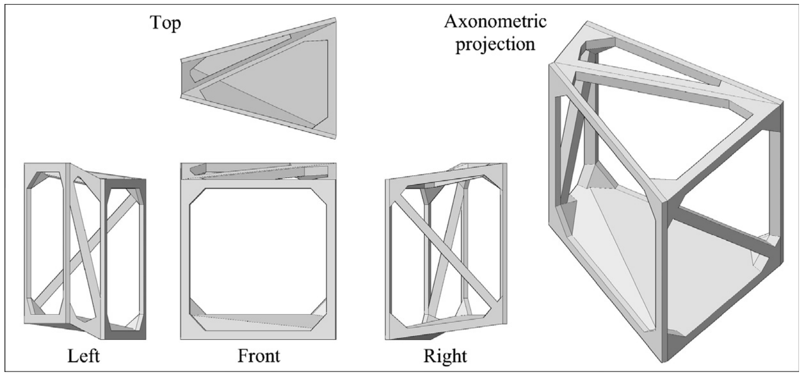

Fig. 1. Planar and axonometric projections of the TZ basic unit.

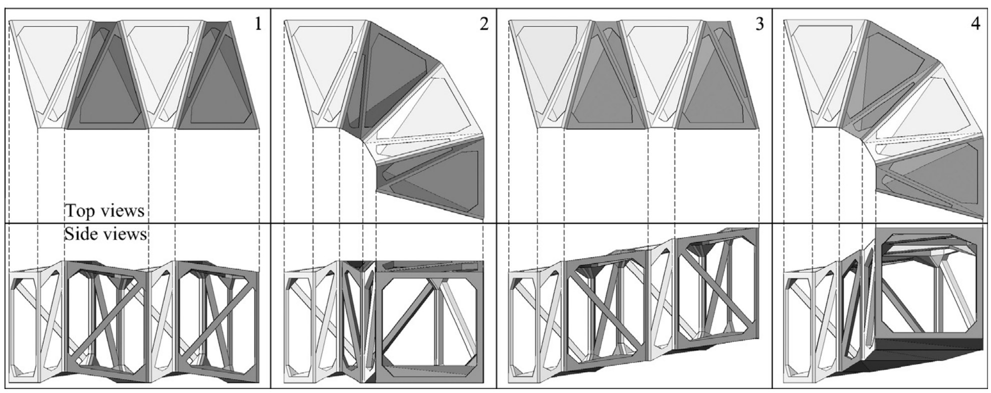

Fig. 2. Some structures composed of four TZ modules: (1) straight-flat (L, L2, L, L2), (2) turn-flat (L, R2, L, R2), (3) straight-up (L, R, L, R), and (4) turn-up (L, L, L, L). The alternating units are shown in contrasting grays for clarity.

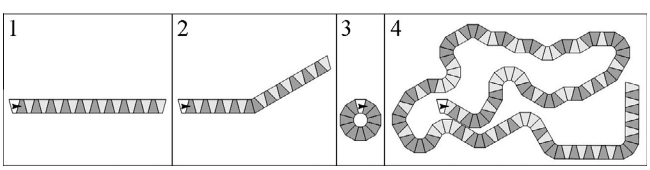

Fig. 3. Various sequences of units 1 and 0, shown in dark and light grays, respectively. The initial unit is shown in white; path directions are indicated by the arrows.

0110001000011111001001000100000111101000101011110100-0101010100001010101. For a corresponding interactive demonstration see [2].

This is an updated and revised version of the conference paper [3] which introduced the evolution strategy (ES) for the optimization of a TZ link connecting two terminals in a given environment. ES which is a classic meta-heuristic method uses the operation of mutation only. In this paper an implementation of genetic algorithm (GA) that employs both mutation and recombination is presented. Two types of recombination are applied: the uniform (UX) and one-point (OPX) crossovers. New series of experiments were performed. A better solution, found by GA is presented and its realistic implementation is visualized. Three additional experiments on different layouts were performed in order to evaluate the universality of the new method.

2. Creating an optimal link between two terminals

A link connecting two terminals is to be created under the following conditions:

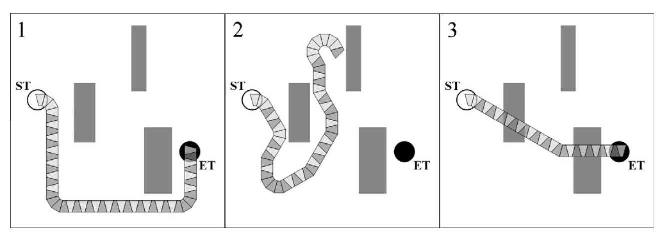

Fig. 4. Two terminals to be linked avoiding the obstacles which are indicated in dark gray. Three paths are shown: (1) a good path with 48 units, (2) an allowable but poor path with 50 units, and (3) the shortest, but non-allowable path with 27 units.

1. There is a given environment defined as:
   1.1.
   two fixed terminals: start (ST) and end (ET),
   1.2.
   there are obstacles as shown in Fig. 4.
2. The path must not collide either with
   2.1.
   itself, or
   2.2.
   any of the obstacles.
3. The initial direction of a path is set arbitrarily.
4. The maximum number of units is arbitrarily limited to 50.
5. The number of units to be minimal.

3. The reference solutions: by manual and backtracking methods

In simple cases, that is when the environment constraints are not very stringent a TZ path can be constructed manually by