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A hybrid evolutionary algorithm for tuning a cloth-simulation model

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ABSTRACT

Textile simulation models are notorious for being difficult to tune. The physically based derivations of energy functions, as mostly used for mapping the characteristics of real-world textiles on to simulation models, are labour-intensive and not guarantee satisfactory results. The extremely complex behaviour of textiles requires additional adjustment over a wide-range of parameters in order to achieve realistic real-life behaviour of the model. Furthermore, such derivations might not even be possible when dealing with mass-spring particle system-based models. Since there is no explicit correlation between the physical characteristics of textiles and the stiffnesses of springs that control a model's behaviour, this remains an unresolved issue. This paper proposes a hybrid evolutionary algorithm (EA), in order to solve this problem. The initial parameters of the model are written in individual's genes, where the number of genes is predefined for different textile types in order to limit the search-space. By mimicking the evolution processes, the EA is used to search the stability domain of the model to find a set of parameters that persuasively imitate the behaviour of a given real-world textile (e.g. silk, cotton or wool). This evaluation is based on the drape measurement, a characteristic often used when evaluating fabrics within the textile industry. The proposed EA is multi-objective, as textile drape is analysed using different quantifications. Local search is used to heuristically improve convergence towards a solution, while the efficiency of the method is demonstrated in comparison to a simple EA. To the best of our knowledge, this problem is being solved using an EA for the first time.

1. Introduction

Considerable research efforts have been dedicated to recreating the realistic appearances and behaviours of cloths for computer simulation. Early computer models of textiles (such as [1–4]) are based on geometric constrains [5]. They are suitable for generating the static shapes of textiles and can produce the realistic appearances of textiles' folds and creases. However, classical geometric representations [6] cannot incorporate the physical properties of textiles. Therefore, the realistic behaviours of cloths cannot be obtained and dynamic physically based models have been needed. One of the earliest physically based models was proposed by Feynman [7]. This model applies the theory of elastic shells as the energy functions employed to define the behaviours of the shells. Free form surface models of cloths are proposed by Trezopoulus et al. in [8–10]. These models utilize a system of differential equations derived from the elastic theory, in order to represent the energy functions of surface deformations. Discretization is achieved either by using a finite difference method or a finite element method, while the solution to the system of equations is found by numerical integration. Further development of Trezopoulus' models is reported by Carignan, who considered self-collision detection in cloth simulation [11]. Continuous models have strong theoretical backgrounds, yet they produce unsatisfying simulation results. The main reason is in the relatively coarse structures of the textiles [12,13]. Various discrete physically based models have been proposed because of this. The approach based on a particle-system, as presented in [12], uses the Kawabata evaluation system (KES) [14] in order to obtain the data needed for the derivations of energy functions. Another particle system, often used in contemporary models, is the mass-spring particle system [15–18]. Each particle has a mass and is connected to neighbouring particles by stretching, bending, and shearing springs [19]. These models are computationally efficient, simple to implement, and achieve good results in real-time applications [13,19,20]. Different methods exist in regard to how formal particle systems [21] are described. One of the most efficient is the so-called Verlet integration [22]. Our application uses its optimization as described by Jakobsen [23]. In this way, the real-time behaviour of the system with self-collision detection has been obtained [24] on an ordinary PC.

In order to achieve the adequate behaviours of computer simulated textiles (e.g. silk, wool, cotton), the physical characteristics of

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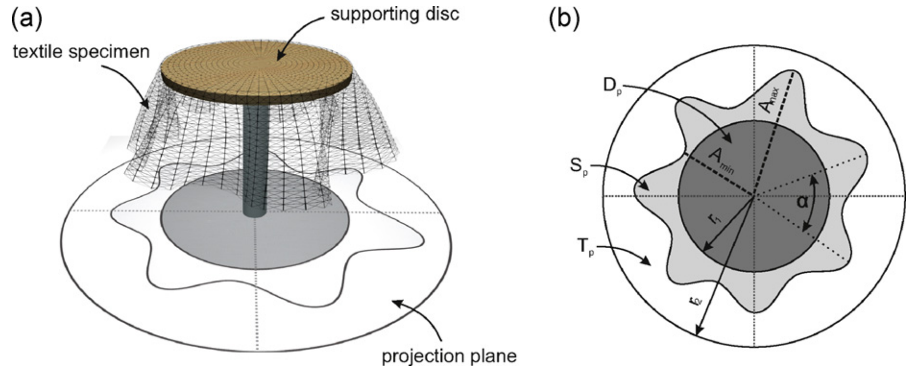

Fig. 1. Drape measurement of fabric; the measurement process (a) and result from the measurement (b).

textiles should be observed. The textile industry acknowledges the drape as a crucial property [25,26]. It describes the extent to which a textile deforms when allowed to hang under its own weight, and is usually measured using a drapemeter [27]. A supporting disc is used for this purpose, in order to hold the textile specimen, as shown in Fig. 1a. The resulting measurement is a projection of the supported disc and the draped textile on an *xy*-plane, as illustrated in Fig. 1b. In an original device, as proposed by Cusick [28], the projection is obtained by outlining the specimen's shadow on a piece of paper, while later modifications by Collier et al. [29] and Kenkare and May-Plumlee [30] use a digital camera for this purpose. Drape analysis can reveal the numerous important physical characteristics of fabrics, such as bending length, shear stiffness, and a full set of cross-term elastic parameters [27,31,32] and is, therefore, frequently used for the evaluation of cloth-simulation models [15].

Unfortunately, mapping the physical characteristics of real-world textiles to the parameters used in discrete real-time modelling systems, is still an unresolved issue [19,20,33]. The physically based derivations of energy equations do not guarantee persuasive real-life behaviour [20] and require the additional tuning over a wider-range of parameters. Achieving realistic behaviour is even more difficult when dealing with real-time mass-spring particle systems. Since there is no explicit relationship between the physical characteristics of the textiles and the parameters of the computer model, they are notoriously difficult to tune [33]. In order to solve this problem, EA is employed. EAs [34,35] are a population-based stochastic optimization search processes that mimic those biological processes that allow populations of organisms to adapt to their environmental surroundings by genetic inheritance, and the survival of the fittest. The main advantage of EAs, over conventional search methods is that EAs do not require any additional information about objective functions, such as differentiability or continuity. Hence, EAs are often used to solve difficult real world problems [36–38].

This paper proposes EA for obtaining representative textile simulation parameters. Section 2 presents the textile model. In Section 3, the proposed EA is explained in details. The results are presented in Section 4, while Section 5 concludes this paper.

2. Simulation model

The proposed textile simulation model is based on a mass-spring particle system. Conceptually, particles represent the crossing points between warp and weft threads, and are arranged within a grid in order to mimic the textiles' structures. Each particle has a mass and is connected to its neighbours in vertical, horizontal, and diagonal directions. By adjusting the stiffness of the springs between the particles, the characteristics of the simulation model (e.g. stretching, bending, and shearing) can be controlled. To achieve persuasive behaviour of the model, each particle is connected to four nearest particles in each direction (see Fig. 2).

The motions of the particles depends on the resultant of outside forces (e.g. gravity, wind, collisions with other objects), and inside forces related to the stiffnesses of the springs connecting the particles. Firstly, during each simulation time-step Δt, the resultant of the outside forces **f** is calculated in order to determine the acceleration of each particle, using the well-known Newton's Motion Law $\mathbf{a} = \mathbf{f}/m$, where m is a particle mass. Using Euler integration, the velocity of a particle $\mathbf{v_i}$ in discrete moments $\mathbf{i} = 0, 1, 2, \ldots, n$ is calculated based on $\mathbf{v_{i-1}}$ and $\mathbf{a_i}$ using Eq. (1), and a new position for particle $\mathbf{x_i}$ is obtained by Eq. (2).

$$\mathbf{v_i} = \mathbf{v_{i-1}} + \mathbf{a_i}\Delta t, \tag{1}$$

$$\mathbf{x_i} = \mathbf{x_{i-1}} + \mathbf{v_i}\Delta t. \tag{2}$$

The optimized integration method proposed by Verlet [22] is used in our case. It avoids intermediate velocity computation by using the previous positions of the particle $\mathbf{x_{i-1}}$ and $\mathbf{x_{i-2}}$. In this way, integration is formulated as follows:

$$\mathbf{x_i} = 2\mathbf{x_{i-1}} - \mathbf{x_{i-2}} + \mathbf{a_i}\Delta t^2. \tag{3}$$

However, the integration method does not consider the loss of energy due to friction within the textile's structure. Therefore, an

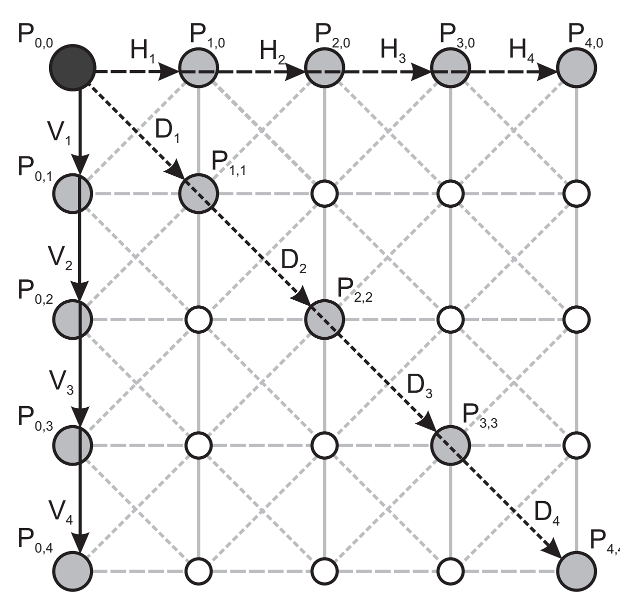

Fig. 2. Connectivity of particles, where particle $P_{0,0}$ is connected to particles $P_{1,0}$, $P_{2,0}$, $P_{3,0}$, $P_{4,0}$ using horizontal springs H_1, H_2, H_3, H_4, $P_{0,0}$ is connected to particles $P_{0,1}$, $P_{0,2}$, $P_{0,3}$, $P_{0,4}$ using vertical springs V_1, V_2, V_3, V_4, and $P_{0,0}$ is connected to particles $P_{1,1}$, $P_{2,2}$, $P_{3,3}$, $P_{4,4}$ using diagonal springs D_1, D_2, D_3, D_4.