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Definition of Mass Spring Parameters for Knitted Fabric Simulation Using the Imperialist Competitive Algorithm

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Abstract
The 3D simulation of fabrics is an interesting issue in many fields, such as computer engineering, textile engineering, cloth design and so on. Several methods have been presented for fabric simulation. The mass spring model, a typical physically-based method, is one of the methods for fabric simulation which is widely considered by researchers due to rapid simulation and being more consistent with reality. The aim of this paper is the optimization of mass spring parameters in the simulation of the drape behaviour of knitted fabric using the Imperialist Competitive Algorithm. First a mass spring model is proposed to simulate the drape behavior of knitted fabric. Then in order to reduce the error value between the simulated and actual result (reducing the simulation error value), parameters of the mass spring model such as the stiffness coefficient, damping coefficient, elongation rate, topology and natural length of the spring are optimized using the Imperialist Competitive Algorithm (ICA). The ICA parameters are specified using the Taguchi Design of Experiment. Finally fabrics drape shapes are simulated in other situations and compared with their actual results to validate the model parameters. Results show that the optimized model is able to predict the drape behavior of knitted fabric with an error value of 2.4 percent.

Key words: *mass spring model, knitted fabric, fabric drape behavior, Taguchi method, Imperialist Competitive Algorithm.*

Introduction

Drape is one of the most important of the apparel properties of fabrics; it is directly related to textile aesthetics. The draping behavior of fabrics has been investigated by many researchers. One of the earliest studies in this area was done by Weil, in which he used geometric equations to model fabric behavior [1]. Another kind of modelling are the physically-based mass spring models, which mainly include finite element models [2-5], particle system models [6-8] and mass spring models. Among these, the mass–spring model is a simple and powerful approach for fabric simulation. Provot first proposed a mass spring model to simulate the 3D shape of a draping fabric [9]. After that, the mass-spring model was modified and developed by several other researchers for simulation of woven and knitted fabric [10-13].

Knitted fabrics are widely used by the apparel industry due to their good comfort, flexibility, elasticity, and formability properties. To model knitted fabrics, various investigations have been carried out, most of which were based on the loop structure [14-15]. However, existing models based on a single loop structure are difficult to apply in practice when used to simulate the draping behavior of fabric due to their complexity and heavy computation. Therefore a general and flexible model for simulating the draping of most types of knitted fabrics is needed. Feng Ji et al. developed a practical mass-spring system to simulate the draping of woven and knitted fabrics. They found in dynamic draping simulation that the knitted fabrics selected have more deformation with smoother appearance than the woven fabrics due to their lower bending [16]. Other researchers also used the mass spring model for simulation of knitted fabric behavior, such as Chen in 2003 [17] and Durupınar in 2007 [18].

One researcher investigated the problem of the difference between theoretical and experimental results. For example, in the mass spring model, it is required to set the model parameters describing deformation behavior. In this regard, a few optimized based approaches have been carried out to recover the mass spring parameters in fabric simulation by correcting the model parameters according to the experimental result. For instance, Louchet et al used the genetic algorithm to optimize the mass spring model parameters in fabric simulation. The model parameters consist of the spring stiffness, elongation rate, and natural length of the spring in stretch, bend and shear cases. They showed the validity of the optimized model by recovering the model parameters in the case of hanging a simulated fabric from two corners [19]. Bianchi et al proposed a solution to spec-

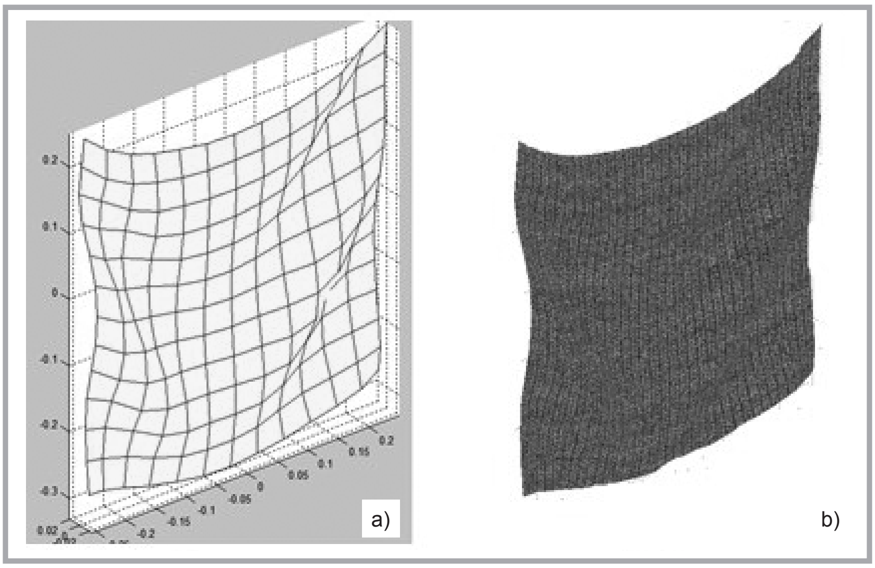


Figure 1. *Fabric sample: a) simulation fabric, b) real fabric.*

ification model parameters based on the genetic algorithm. Their focus was the determination of mesh topology in 2D simulation. They used the Finite Elements Model (FEM) to obtain the topology of a mass spring model. Their work results demonstrated that the genetic algorithm is able to recover the topology of the mass spring model, and spring connections were successfully identified [20]. In the subsequent work, they extended their method to the 3D model. Furthermore they introduced a new approach to simultaneously optimize mesh topology and spring stiffness values. Linear elastic FEM deformation computations were used as reference for the model confirmation [21]. Han et. al considered a range of parameter values for the mass spring model (bending stiffness, stretch stiffness, and shear stiffness) for fabric simulation, and in order to achieve the highest compliance, they determined appropriate values for these three model parameters by using the trial and error method [22]. Mongus et al. used the genetic algorithm to find the best values for stretch and shear spring stiffness coefficients in mass spring modeling for fabric simulation. Optimization was done through error minimization between the model and experimental results. They used two indexes in the objective function to compare simulated and real fabric behavior: the drape coefficient (DC) and distribution of folds. Different textiles may produce the same DC but they differ in the number, amplitude and distribution of folds. Therefore they used the Fast Fourier Transformation to measure these properties [23].

The novelties of this paper is proposing a new and effective technique through optimization model parameters to generate a realistic simulation of knitted fabric drape. So far, no research has been done using the Imperialist Competitive Algorithm (ICA) for optimization of the mass spring model in fabric simulation. Therefore the purpose of this paper is determining an appropriate model to simulate the drape behavior of knitted fabric by using the Imperialist Competitive Algorithm (ICA). In the first part of this paper, it will be necessary to describe a system to visually build a realistic simulation of fabric using a physically based mass spring model. Then a meta-heuristic method based on the Imperialist Competitive Algorithm (ICA) is presented to identify the model parameters from given geometric data. For collecting these data, the drape behavior of nine different types of knitted fabrics hanging from four fixed corners were measured. To achieve the highest precision and accuracy of the optimization algorithm, the ICA parameters are tuned using the Taguchi Design of Experiment. Finally in order to check the model verification, the drape deformation of simulated fabric is compared with the real behavior of fabric in other situations (two fixed corners). The results presented show the ability of the ICA algorithm to recover the mass spring parameters in fabric simulation.

Problem definition

Fabric simulation is the result of the combination of various methods that have dramatically evolved during the past decade. However, there still exit some limitation, one of which in the fabric modeling problem is the difference between real and simulation results (***Figure 1***). Researchers who have considered this problem in their work are few because the research has been mainly devoted to computer graphics and not especially to textile engineering. Most researchers are looking for new techniques to increase speed in fabric simulation in real time [24-28].

However, in the field of textile engineering, realistic simulation of fabric is more important than real time simulation. Realism is usually used as a criterion to evaluate the accuracy of simulation, and plays an important role in achieving this. This may be important especially in the textile industry, since it leads to the saving of time and money by preventing the production of garments that will not be sold.

Also realistic simulation is especially important in cloth design software, which can be useful as follows:

- Simulating cloth without costing countless hours.
- Saving from guessing how clothes should fit in real life.

Therefore the aim of this paper is to present a new and effective technique to generate realistic simulation of knitted fabric drape. In order to reduce the difference between real and simulation results, the following strategy can be used :

- Proposing an accurate and appropriate model that can simulate the real behavior of fabrics.
- Optimization model parameters using the optimization method such as the meta-heuristic technique.
- Application of more accurate environmental conditions mentioned for fabric simulation, such as external forces.

In this work, for achieving realistic simulation, a second strategy i.e. optimization model parameters is mentioned. Thus the Imperialist Competitive Algorithm is used as an effective and powerful algorithm in optimization. Optimization is carried out through comparison of real and simulation results.

Physical model

In this paper, the mass spring model is used to simulate the drape behavior of knitted fabric. The mass-spring model is a popular method of deformable modelling,, discretisising the objects simulated into a set of masses that are interconnected by springs and dampers.

Mesh

In the mass spring model, fabric is represented as a grid of mass points called a mesh, in which connections between the mass points are through elastic linkage (spring). Each mass point has a position, velocity and acceleration and responds to both internal and external forces. By considering the linkage between mass and springs, different types of mesh have been presented by researchers [9].

Forces analysis

In the mass spring model, the position of each particle depends on both the internal and external forces applied. And the position of all particles reflects the appearance of the fabric. The position of each particle is determined by Newton's second law, in accordance with ***Equation 1***.

$$F = ma \qquad (1)$$

Where m is the mass of the particle, a the acceleration of the particle and F is the sum of both internal and external forces applied on the particle.

Internal forces determine the mechanical properties of the fabric and mainly include stretch, shear and bend forces. The internal forces at each mass point are the whole results from the forces of all springs linking this point to its neighbors. According to ***Figure 2***, the internal force in P_i can be represented as ***Equation 2***.

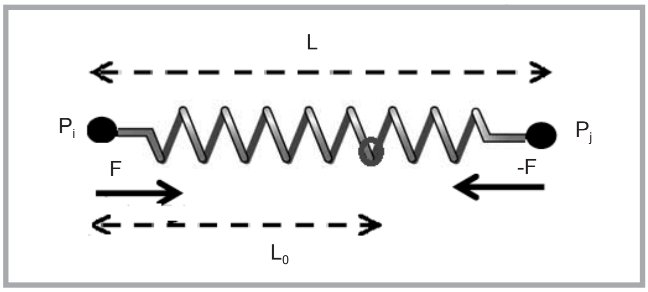
$$F(P_i) = -K(L - L_0) \qquad (2)$$

Where L is the spring length, L_0 the natural length of the spring, F the force applied at P_i and K is the spring stiffness coefficient connecting P_i and P_j [9].

Super elasticity effect

In the method of fabric simulation based on the spring-mass model, if the behavior of force-elongation is assumed to be linear, when a small element of the fabric is exposed to a large concentrated force, large spring deformation will cause unnatural stretching and compression of fabric simulation. This phenomenon is called the super elasticity effect. However, this assumption is not true and large deformation does not appear in the real fabric [29]. Some methods have been presented by researchers to settle the super elasticity problem.

Figure 2. *Spring force between two mass points.*



Methods of numerical integration

To solve the differential equations of physical simulation based on the mass spring, integration is needed, which is a process of simulation for calculating mass point positions and velocities in the fabric model by considering the force applied at the points.

Strategy of determining model error

In order to correct model parameters, determining the model error is important. The model error is referred as the difference between positions of particles as predicted by the model and actual positions of particles. Since most changes in the position of particles occur at the edges of the fabric, in this paper the position of particles at the fabric edge in the real and simulated fabric are compared to each other. For this purpose, a number of point positions against the reference position at the fabric edges are fitted to the polynomial equation in the real and simulation image, as shown in ***Figure 3***. The polynomial equation can more accurately show fabric behavior when the degree of the polynomial is higher. Then the difference between the fitted polynomial equation coefficients for real and simulated fabrics get minimised by the optimisation model parameters.

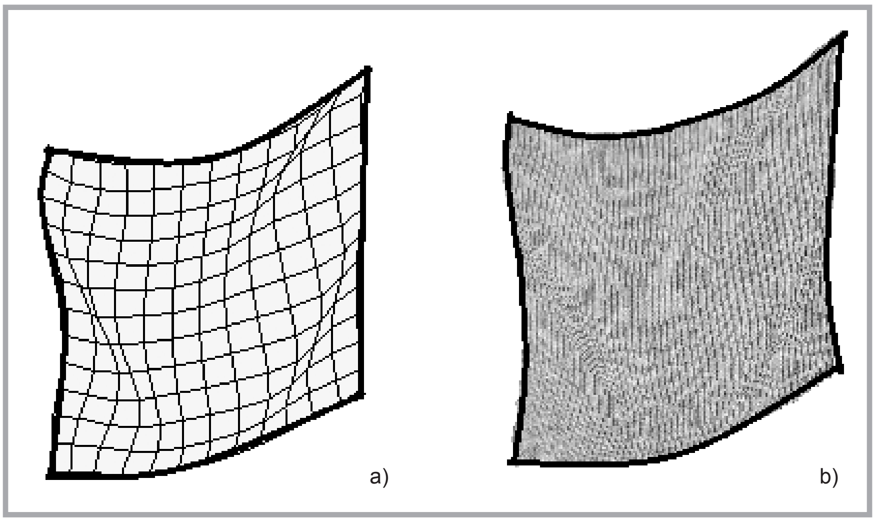


Figure 3. *Curve of the fitted polynomial equation in: a) simulated fabric, b) real fabric.*

Strategy of optimisation model parameters

In the mass spring model, parameter identification (spring stiffness coefficient, damper coefficient, mesh topology, and spring length) still remains a challenge. Since there is no explicit relationship between the physical characteristics of the fabric and the parameters of the model, they are notoriously difficult to be tuned. Thus the aim of this paper is to find the best value for the model parameters through minimisation of the error value between the actual and predicted results. Model parameters that were selected to be optimized are as follow:

Mesh topology

To identify the best topology parameter, three types of mesh topologies are considered as follows:

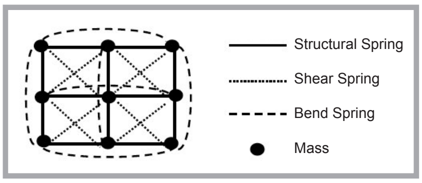


Figure 4. Mesh topology: mesh with stretch, shear and bending springs.

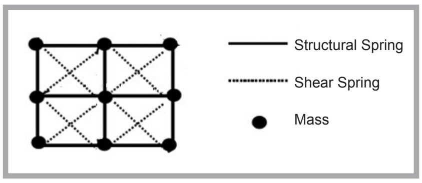


Figure 5. Mesh topology: mesh with stretch and shear springs.

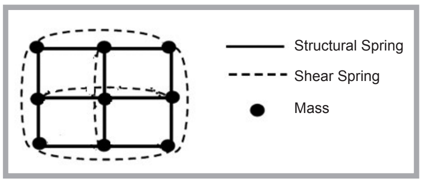


Figure 6. Mesh topology: mesh with stretch and bending springs.

Mesh with stretch, shear and bending springs

In this mesh, the fabric model is constructed by a rectangular grid of mass points (also called particles). Each particle has a mass and is connected to its neighbors in vertical, horizontal, and diagonal directions (see ***Figure 4***). There are three different types of springs in the mesh defined as follows:

1) Structural springs,
2) Shear springs,
3) Bending springs.

Mesh with stretch and shear springs

In this mesh, each particle has a mass and is connected to its neighbors in vertical, horizontal, and diagonal directions (see ***Figure 5***). There are two different types of springs in the mesh defined as follows:

1) Structural springs,
2) Shear springs

Mesh with stretch and bending springs

In this mesh, each particle has a mass and is connected to its neighbors in vertical and horizontal directions. (See ***Figure 6***). There are two different types of springs in the mesh defined as follows:

1) Structural springs,
2) Bending springs.

Spring stiffness

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. In order to reduce algorithm computation, the model was simplified. It was assumed that all the springs (stretch, shear and bending) share a common stiffness value. According to some researches, this assumption can be acceptable in simulation results [19, 30-32].

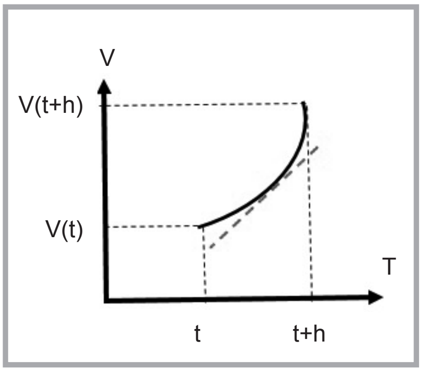


Figure 7. Explicit Euler method.

Damper coefficient

The role of damping is, in fact, to model the approximation of the dissipation of the mechanical energy of the model.

Elongation rate

The elongation rate is related to the maximum deformation rate of the model.

Natural length of spring

This parameter determined the number of mass points in the model.

Other model parameters were constant, as follows:

Super elasticity effect

In this paper, the position correction method is used to overcome the *Super elasticity* problem. In this method, deformation rates of all springs are computed at each time step. If the deformation rate of a spring is greater than the critical threshold, then the two ends of the spring move toward each other along their axis, and hence its deformation rate exactly equals the critical threshold.

Methods of numerical integration

Euler Explicit method: In this method, the end position of the time step will be predicted using the slope (first derivative) at the beginning of the time step, shown in ***Figure 7*** [33].

Environment condition

The environment condition or external forces are varied according to the environment condition which is mentioned for fabric simulation. In this paper, gravity and damping forces are considered as external forces. The gravity force applied at each point is defined as ***Equation 3***.

$$F_{gravity} = mg \tag{3}$$

Where m is the particle mass, g the acceleration of gravity, and $F_{gravity}$ is the gravity force.

The damping force is necessary to maintain the stability of the system. The role of this damping is, in fact, to model the dissipation of the mechanical energy of the model. The damping force can be represented as ***Equation 4***.

$$F_{damping} = -C_{damping} V \tag{4}$$

Where $F_{damping}$ is the damping force, $C_{damping}$ the damping coefficient, and V is the particle velocity.

Imperialistic Competitive Algorithm

The Imperialistic Competitive Algorithm (ICA) is an innovative evolutionary optimization method which is inspired by imperialistic competition [34]. ICA starts with some random initial population, each called a "Country". Some of the best countries in the population are selected as "Imperialists", while the rest are considered as "Colonies". Imperialists can dominate colonies depending on their power. The power of each empire depends on two parts: imperialist as a main core and the colonies. In the mathematical model, it is modelled by the imperialist power in addition to a few percent of the colonies' power. With the formation of initial empires, imperialist competition is started. Each of the imperialists will be removed if it cannot develop its power (at least prevent a decrease in its power). Hence the survival of each empire is dependent on absorbing other empires' colonies. Accordingly in imperialist competition, stronger empires gradually develop their power and weaker empires will be eliminated. The empires must develop their colonies to improve their power. Over time, colonies' power will be closer to the imperialist's power and a convergence will be seen. When only one empire exists, the algorithm is terminated. In this condition, the power of the empire's colonies is very close to

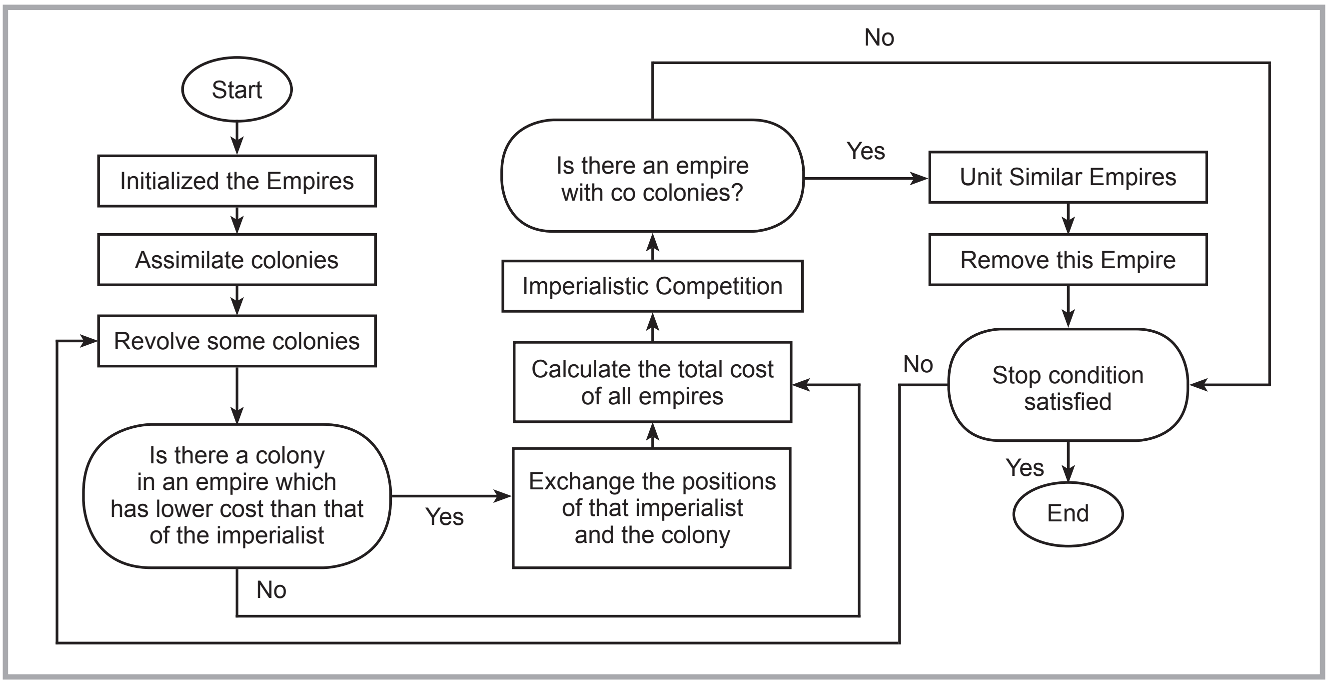


Figure 8. ICA flowchart [35].

the empire's power. Details of the ICA approach are illustrated in the flowchart in ***Figure 8*** [35].

ICA parameter tuning

One of the important components of the Imperialist Competitive Algorithm is the calibration of parameters which impress upon the performance of the algorithm. To definie ICA parameter values and investigate how the mean and different parameters affect the model performance proposed, The Taguchi Design of Experiment is utilised**.**

Taguchi method

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and is a powerful tool for the design of high quality systems [36]. It is commonly used in improving industrial product quality due to the proven success. With the Taguchi method, it is possible to significantly reduce the number of experiments. The Taguchi method is not only an experimental design technique, but also a beneficial technique for high-quality system design. This technique helps to study the effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined.

The general steps in the Taguchi Method are illustrated in the flowchart in ***Figure 9***.

1. Define the process objective, or more specifically, a target value for a performance measurement of the process. The target of a process may be a minimum or maximum; for example, the goal may be to maximize the output or minimization.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measurement and can be easily controlled.
3. Create orthogonal arrays for the parameter design indicating the number and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and levels of variation for each parameter.
4. Conduct the experiments indicated in the completed array to collect data that effect the performance measurement.
5. Complete data analysis to determine the effect of the different parameters on the performance measurement.

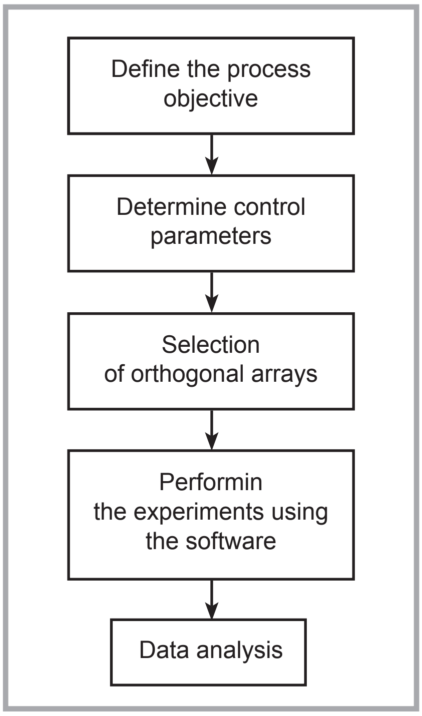


Figure 9. Taguchi flowchart.

Table 1. *Parameters of ICA and their levels.*

Control parameters		Level		
		1	2	3
A	Number of generation (*MaxIt*)	10	20	40
B	Number of imperials (N_{imp})	15	20	25
C	Number of countries ($N_{country}$)	2	5	10
D	Assimilation coefficient (β)	0.5	1	2
E	Assimilation angle coefficient (γ)	0.1	0.3	0.5
F	Revolution rate	0.2	0.3	0.4
G	Colonies share coefficient (ξ)	0.1	0.15	0.2

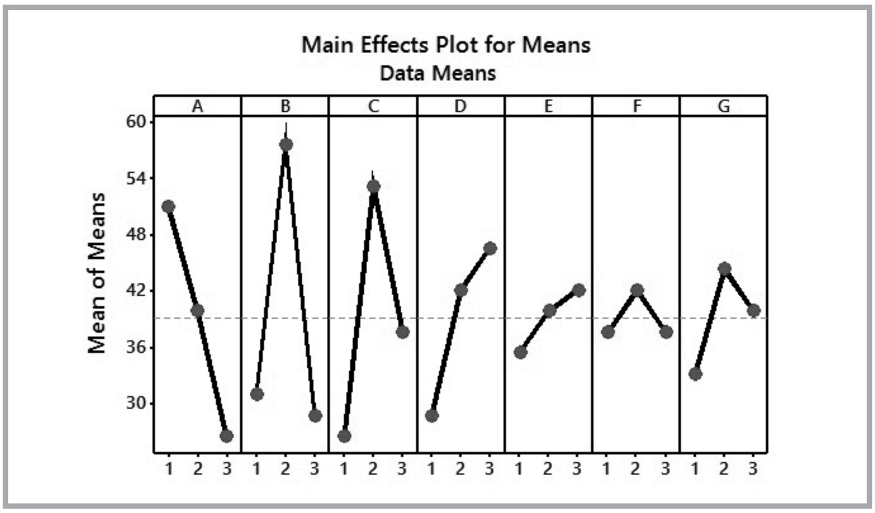


Figure 10. *Mean S/N ratio plot for each level of ICA factors.*

Taguchi categorizes the objective functions (***Equation 2***) into three groups: (I) smaller-the-better type, larger-the-better type, and nominal-is-the-best type. In this work, the smaller the-better type is selected according to the objective function.

The important stage in the design of the experiment is the selection of the control factors. ***Table 1*** (see page 69) represents ICA parameters used for initializing the optimisation process. These parameters have been allowed to vary at three different levels.

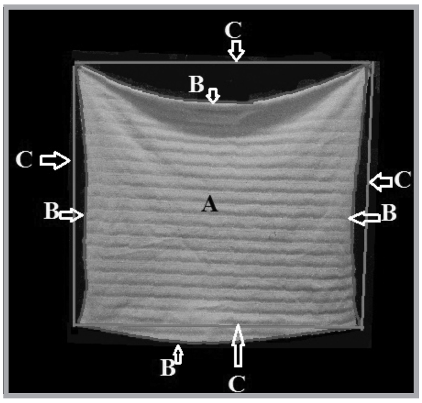


Figure 11. *Drape test for two fixed corners: A) fabric sample, B) curve of fitted polynomial equation, C) reference position.*

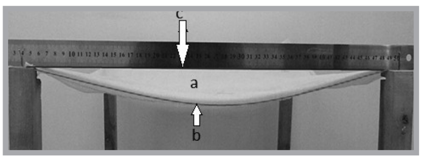


Figure 12. *Drape test for four fixed corners: a) fabric sample edge, b) curve of fitted polynomial equation, c) reference position.*

By referring to the Taguchi standard arrays table, orthogonal arrays L_{27}, as the most suitable design, is used to tune the ICA parameters. To generate the Taguchi result, Minitab software is used and each example is run for every level of each factor. ***Figure 10*** shows the S/N ratio plot for each level of the factors of ICA. After the experimental design for the problem mentioned, the results obtained by the Taguchi method indicated that A (3), B (3), C (1), D (2), E (1), F (2) and G (2) is the best combination of parameters for ICA.

Experimental

The model proposed is used to simulate the drape behaviour of 9 different samples of knitted fabric hanging from four fixed corners. Fabric specimens (100% Polyester) were produced on a circular knitting machine. The specifications of 9 samples are illustrated in ***Table 2***. Before taking any measurements, all fabrics were placed on a flat surface for 24 hours in standard atmospheric conditions of 23 ± 2°C and 65 ± 2% RH.

There are five stages in the drape test as follows:
- Fabric samples are cut to 50*50 cm^2.
- Fabric samples are hung under their weight from two and four fixed corners in standard atmospheric conditions.
- A drape deformation image of the fabric samples is taken with a Nikon COOLPIX P80 10 M pixel camera.
- Stages 2 and 3 are repeated five times for each sample, and the average data are considered to reduce measurement error.
- The drape deformation of the fabric samples are extracted from fabric images. To this point, a number of point positions against the reference position at the fabric edges are fitted to the fourth-order polynomial equation.

Figures 11 and ***12*** show the drape test on sample (1) for two and four fixed corners, respectively. In this figure, the fitted polynomial equation (marked red) and the reference position (marked blue) are specified.

Optimization of model parameters using ICA

In this section, the optimization procedure of the model parameters based on the ICA approach is presented. The model contains 5 parameters:
- Spring stiffness
- Damper coefficient
- Elongation rate
- Natural length of spring
- Mesh topology

The model parameters and their limits are determined by considering the initial tests (based on trial and error), shown in ***Table 3***. To identify the topology parameter, three types of mesh topologies are considered, illustrated in ***Figures 4-6***.

Table 2. *Specifications of samples.*

No.	Material	Weight, g/m^2	Weave	Yarn count, Denier	Wale density, Cm^{-1}	Course density, Cm^{-1}	Loop density, Cm^{-1}
1	Polyester	41.65	Plain	100	14	12	168
2	Polyester	44.14	Plain	150	14	14	196
3	Polyester	46.76	Plain	150	20	20	400
4	Polyester	44.63	Plain	150	14	12	168
5	Polyester	49.62	Plain	100	22	14	308
6	Polyester	27.6	Plain	100	12	12	144
7	Polyester	51.16	Plain	150	22	34	748
8	Polyester	54.41	Plain	150	22	32	704
9	Polyester	58.26	Plain	150	22	32	704

Determining the ICA objective function

The objective function evaluates the accuracy of the model parameters. In this regard, first the drape shapes of fabric samples are completely simulated according to the model parameters. Then a number of point positions against the reference position at the fabric edge are fitted to the fourth-order polynomial equation to extract the fabric drape deformation in both the real and simulated fabric images. In the ICA, it is necessary that the difference between fitted polynomial equation coefficients for real and simulated fabrics get minimised. If this difference in the value is less, the simulated image will be closer to the real image. Hence the general cost function can be defined by ***Equation 5***. In ***Equation 5***, the value of the equation is equal to the simulation error.

$$objectiv\ \ function = \sqrt{\frac{\sum_{i=1}^{5} (P_{ei} - P_{si})^2}{5} \times 100} \quad (5)$$

Where P_{ei} are the polynomial equation coefficients of the real fabric images, and P_{si} are the polynomial equation coefficients of the fabric images simulated by the model.

If the cost function involves positions related to all time steps, it will have a high computational cost. Thus the cost function only involves the time step related to the fabric equilibrium position in the simulation.

Results and discussion

The tuned ICA by the Taguchi method is used to optimise the model parameters. Heuristic optimization algorithms should be sufficiently repeatable to achieve the same solution (or near the solution) in repeated runs. Therefore after 10 runs of the algorithm for each sample, the best results are selected.

The optimization is performed by Matlab2014 software and a computer with the following specifications: Cori7, 740Qm, 1.74 GHZ, Ram 8 GB. Optimized parameters for all the samples are determined, which are discussed in next section in full.

Figure 13 shows the objective function variations in every decade during the optimization process for sample 1. It clearly indicates the convergence of the optimization process. By increasing the number of decades, the mean value of the objective function shows decreasing behaviour which gradually reaches the best value. The ICA finds the best value very rapidly in early decades.

After 10 runs, the best values of the model parameters are selected for 9 samples hanging from four fixed corners. The results of optimized parameters and the objective function values are presented in ***Table 4***.

As shown in ***Table 4***, the model presented is able to predict the drape behavior of knitted fabric hanging from four fixed corners, and the mean error value of 9 different types of knitted fabrics is 1.6 percent.

As shown in ***Table 4***, sample 9 presents the highest spring stiffness, because it is the heaviest fabric among all the samples. However, sample 6 is the lightest fabric and has the smallest spring stiffness among the nine fabrics. Similar results are also observed for the density parameter; the spring stiffness increases as the loop density rises.

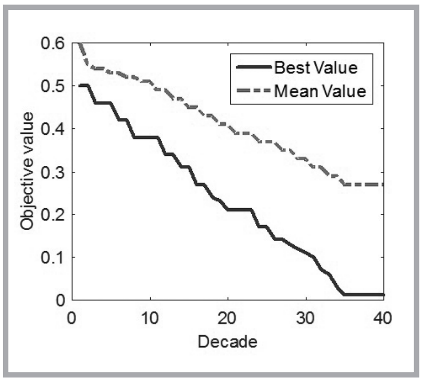


Figure 13. *Best and mean values of the objective function for the ICA approach for sample1.*

Table 5 (see page 72) presents figures of the fabric simulation generated using the optimized model for the 9 kinds of fabric samples hanging from four fixed corners. A comparison between the fitted polynomial equations for fabric edges in the simulated and real fabric images is presented in ***Table 5***.

Table 3. *The model parameters and their limits.*

Parameters	Lower limit	Upper limit
Spring stiffness, N/m	500	1200
Damper stiffness, N.s/m	10	20
Elongation rate, %	5	20
Natural length of spring, cm	4	6

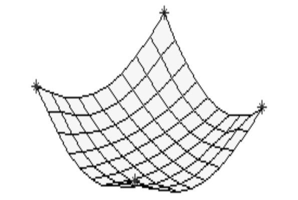
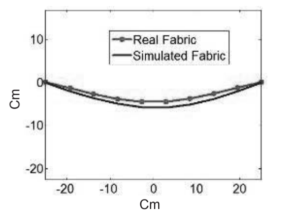
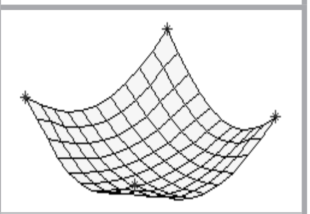
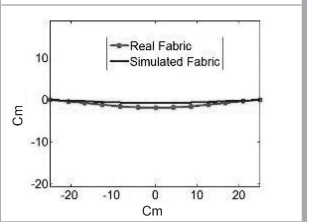
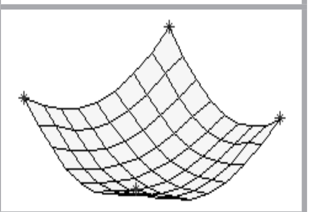
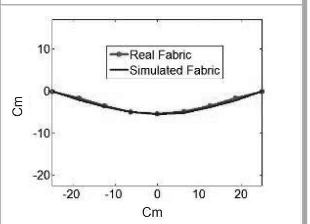
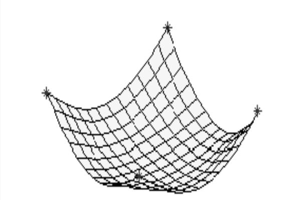
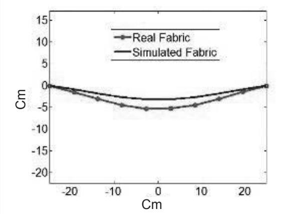
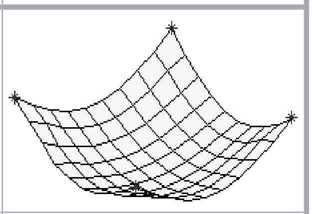
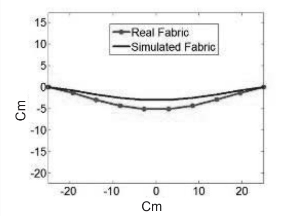
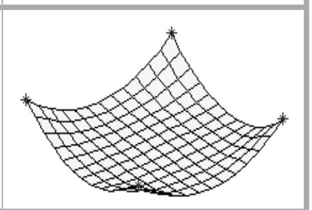
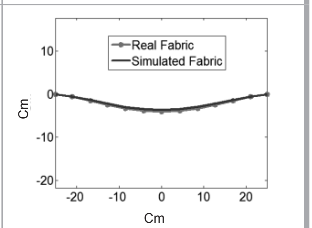
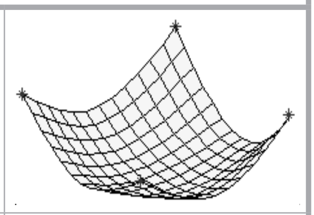
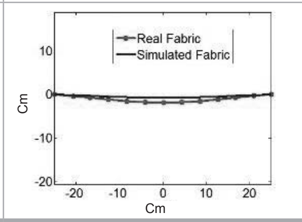
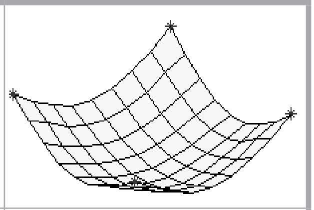
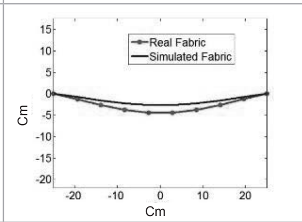
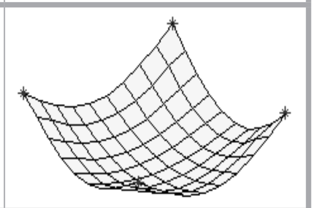
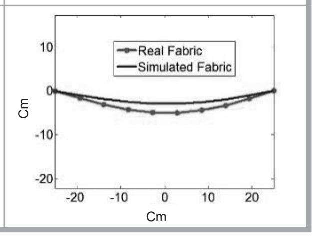
Table 4. *Optimal and error percentage values for 9 samples hanging from four fixed corners.*

No.	Spring stiffness, N/m	Natural length of spring, cm	Elongation rate, %	Damper coefficient, N.s/m	Mesh topology	Error (objective function), %
1	852	49	5	12	Type a	1.1
2	942	47	7	10	Type a	0.7
3	988	53	6	10	Type a	0.4
4	945	40	5	10	Type a	2.5
5	1034	49	7	11	Type a	2.5
6	674	40	5	10	Type a	0.3
7	1092	40	5	10	Type a	2.2
8	1100	55	6	10	Type a	2.6
9	1100	50	5	13	Type a	2.4

Table 6. *Optimal and error percentage values for 9 samples hanging from two fixed corners.*

No.	Spring stiffness, N/m	Natural length of spring, cm	Elongation rate, %	Damper coefficient, N.s/m	Mesh topology	Error (objective function), %
1	852	49	5	12	Type a	2.5
2	942	47	7	10	Type a	2.3
3	988	53	6	10	Type a	2.7
4	945	40	5	10	Type a	2.7
5	1034	49	7	11	Type a	2.2
6	674	40	5	10	Type a	2.5
7	1092	40	5	10	Type a	2.5
8	1100	55	6	10	Type a	2
9	1100	50	5	13	Type a	2,6

Table 5. Simulated image of 9 fabric samples hanging from four fixed corners.

No		
1	Simulated fabrics	
	Fitted polynomial	
2	Simulated fabrics	
	Fitted polynomial	
3	Simulated fabrics	
	Fitted polynomial	
4	Simulated fabrics	
	Fitted polynomial	
5	Simulated fabrics	
	Fitted polynomial	
6	Simulated fabrics	
	Fitted polynomial	
7	Simulated fabrics	
	Fitted polynomial	
8	Simulated fabrics	
	Fitted polynomial	
9	Simulated fabrics	
	Fitted polynomial	

To prove the accuracy and precision of the optimized model, the model's ability to predict drape behavior should be evaluated with other positions of fabric. Thus in this stage, the drape deformations of fabric samples in other situations (two fixed corners) are simulated using the optimized parameters that are shown in ***Table 4***. Then the simulated fabric behavior is compared with the real fabric. ***Table 6*** (see page 71) shows the optimized parameters and error percentage values for each sample.

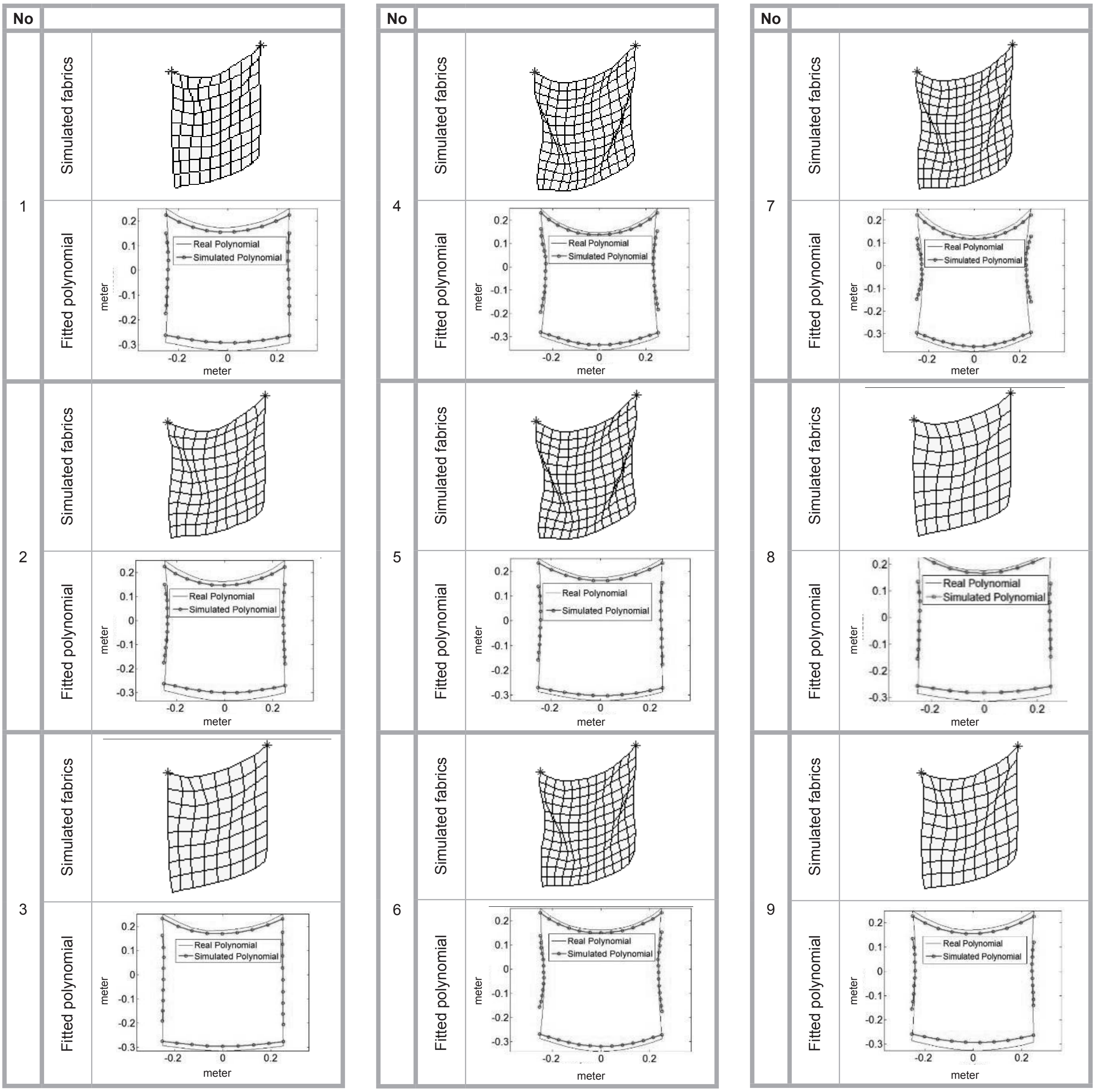
Table 7 presents figures of the fabric simulation generated using the optimized model for 9 kinds of fabric samples hanging from four fixed corners. In this simulation, 4 polynomial equations are obtained according to four fabric edges. A comparison between the fitted polynomial equations for fabric edges in the simulated and real fabric images is presented in ***Table 7***.

In ***Table 7***, it is observed that the mean error value in predicting the knitted fabric drape behavior from two fixed corners is 2.4 percent. Therefore the mass spring parameters for fabric simulation in the various positions can be determined by using the optimization methods, such as the ICA.

Conclusion

In this paper, the drape behavior of knitted fabric is simulated by the mass spring model. In order to increase the model accuracy, its parameters, including the stiffness coefficient, damping coefficient, elongation rate, topology mesh and natural spring length, are optimized using the Imperialist Competitive Algorithm (ICA). Then the ICA parameters are specified using the Taguchi Design of Experiment to achieve the highest efficiency. After determining the optimized parameters, the drape behavior of knitted fabric samples hanging from four

Table 7. *Simulated images of 9 fabric samples hanging from four fixed corners.*



fixed corners are simulated using the optimized model and then compared with the real fabric behavior. It was found that the mean error value of 9 kinds of fabrics is 1.6 percent. To prove the accuracy and precision of the optimized model, the model's ability to predict fabric behavior in a new position should be investigated. Therefore the drape deformations of fabric samples in other situations (two fixed corners) are simulated using the optimized parameters. It is observed that the optimized model is able to predict the drape behavior of knitted fabric with an error value of 2.4 percent.

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