FABRIC MODELING : CONVERGENCE CALCULUS OPTIMIZATION

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INTRODUCTION

The goal of our research works is to build a software for fabric modeling. Our research team wants to simulate any fabric deformations due to mechanic stresses.
This paper deals with our solutions to speed up calculus convergence of fabric model simulation. These solutions are based on clever propagation algorithm, multi sampling and displacement prediction.
Into bibliography, there is several models based on stress-geometric approach as [8-23] and others based on finite element method (FEM) as [1-7]. Our approach, more ambitious, is based on a scale swap from yarn to fabric. Indeed, from mechanical properties of yarn and its geometric shape into fabric, our model simulates fabric behavior under mechanical stresses.
First, we present quickly our fabric model. Then, the solutions to speed up simulation calculus are exposed.

DYNAMIC FABRIC MODELING

Unlike the others fabric models, for our works, we decided to model fabric from yarn properties and fabric datas. In fact, fabric is yarn interlacing. Fabric is sampling with crossing points. This crossing point is the base element of our model. Then, fabric is modeled by spring links between neighbor crossing points. Every point is linked to close neighbors by four spring links as show in figure 1.

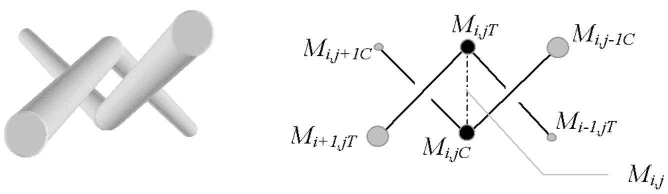


Figure 1 : base element of our model

The base element of our model Mi,j is considering as keep shaping, according the assumption that there is no slip between warp yarn and weft yarn. Such a mesh model of 2D fabric from a 3D representation to 2D one.
Representation is shown on Figure 2.

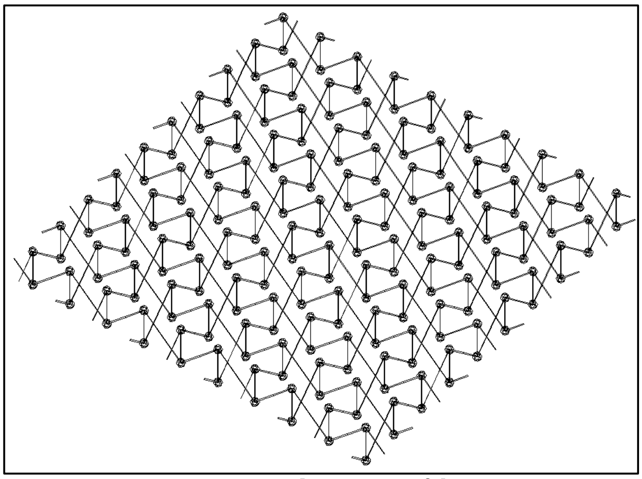


Figure 2 : plain weave fabric

From stresses statement on one crossing point Mi,j, it possible to write the equation of mass point move [22]. Figure 3 present our symbols.

$i \,\&\, j$ position of one crossing point into 2D meshing,
$C \text{ or } T$ symbolized Warp or Weft,
$m_{i,j}$ mass of two half warp springs and two weft springs,
$n_{i,j}$ coefficient of air viscosity,
$q_{i,j\,C}$ angle between two warp springs,
$q_{i,j\,T}$ angle between two weft springs,
$\overset{®}{u}_{i,j,C}$ displacement vector of $M_{i,j\,C}$,
$\overset{®}{u}_{i,j,T}$ displacement vector of $M_{i,j\,T}$,
$\overset{®}{u}_{i,j}$ displacement vector of $M_{i,j}$,
$\overset{®*}{R}_{i,j}$ external fabric stresses sum,
$\overset{®}{g}$ gravity,
$\overset{®}{F}_{ext,\, i,j}$ stresses on fabric,
$\overset{®}{F}_{jamming}$ jamming stresses,
$\overset{®}{H}(\overset{®}{u}_{i,j})$ internal fabric stresses sum,
$\overset{®}{F}_{tr,\, i-1,j,i,j} \,\&\, \overset{®}{F}_{tr,\, i,j,i+1,j}$ stress due to yarn traction behavior,
$\overset{®}{F}_{fl,\, i,j,C} \,\&\, \overset{®}{F}_{fl,\, i,j,T}$ stress due to yarn bending behavior,

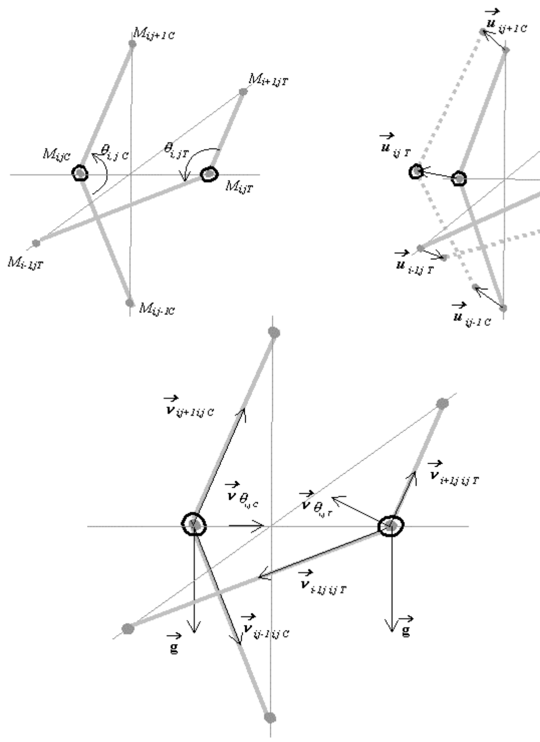


Figure 3 : notation set

So, Newton law could be written, calling $\vec{u}_{i,j}$ the displacement of point $M_{i,j}$ as :

$$\vec{R}^*_{i,j} = m_{i,j}\frac{d^2\vec{u}_{i,j}}{dt^2} + n_{ij}\frac{d\vec{u}_{i,j}}{dt} - \vec{H}(\vec{u}_{i,j}) \qquad (1)$$

with

$$\vec{R}^*_{i,j} = m_{i,j,C}\,\vec{g} + m_{i,j,T}\,\vec{g} + \vec{F}_{ext,\,i,j} + \vec{F}_{jamming} \qquad (2)$$

and

$$\vec{H}(\vec{u}_{i,j}) = \vec{F}_{tr,\,i-1,j,i,j} + \vec{F}_{tr,\,i,j,i+1,j} + \vec{F}_{tr,\,i,j-1,i,j} + \vec{F}_{tr,\,i,j,i,j+1} + \vec{F}_{fl,\,i,j,C} + \vec{F}_{fl,\,i,j,T} \qquad (3)$$

Equations (1), (2) et (3) are movement equations of crossing point $M_{i,j}$. Remark that equation *(1)* is a non linear one. [19-23]

INTEGRATION METHOD AND OPTIMISATION

Integration of the dynamic system

Equation (1) is a non linear ODE which could be written at time *t* as :

$$R^*(t) = m\frac{d^2u(t)}{dt^2} + n\frac{du(t)}{dt} + H(u(t)) \qquad (4)$$

In order to integrate equation (4), time ***t*** is sampled by a sampling period ***te*** (so ***t=nte***). Value of te is obtained following SHANNON theorem. Because this value is very small (about ***10-7 s***), we choose finite differences method as follows.

Equation (4) is integrated by successive steps. First, we defined :

$$R(t,u(t)) = R^*(t) + H(u(t)) \qquad (5)$$

so :

$$R(t,u(t)) = m\frac{d^2u}{dt^2}(t) + n\frac{du}{dt}(t) \qquad (6)$$

then, we set the dynamic system :

$$\begin{cases} Rn = R(n\,te, u(n\,te)) \\ \frac{du}{dt}(n\,te) = V(n\,te), m\frac{dV}{dt}(n\,te) + n\,V(n\,te) = Rn \end{cases} \qquad (7)$$

and, with Finites Differences method, we have :

$$\frac{dV}{dt}(nte) = \frac{V((n+1)te) - V((n-1)te)}{2\,te} \qquad (8)$$

and

$$\frac{du}{dt}(nte) = \frac{u((n+1)te) - u((n-1)te)}{2\,te} \qquad (9)$$

system *(7)* could be written :

$$\begin{cases} Rn = R(n\,te, u(n\,te)) \\ V((n+1)te) = \frac{2\,te}{m}(Rn - n\,V(n\,te)) + V((n-1)te) \\ u((n+1)te) = 2\,te\,V(n\,te) + u((n-1)te) \end{cases} \qquad (10)$$

Such integrating solution gives good results but calculus times is too important [19-20]. Therefore, we developed specific solutions.

Optimization of convergence calculus

The first adopted solution in order to speed up convergence to fabric dynamic balance has been set from a fine analyze of yarn deformation leading to fabric deformation. Indeed, one crossing point would have a non null displacement if one of its neighbors has a non null displacement.

A clever propagation algorithm has to follow displacement information of one point to others and a rank is set to each point according its neighbor ranks.

On the example of figure 4, fabric is under traction stresses. Points $M_{1,1}$ to $M_{1,6}$ are set fitting (rank 0). Points $M_{6,1}$ to $M_{6,3}$, are stressed (rank 1). In that case, the first points moved by displacements of points $M_{6,1}$ to $M_{6,3}$ are $M_{5,1}$, $M_{5,2}$, $M_{5,3}$, $M_{6,4}$. Theirs ranks are rank 2. Points with rank 3 are points $M_{4,1}$, $M_{4,2}$, $M_{4,3}$, $M_{5,4}$, $M_{6,5}$.

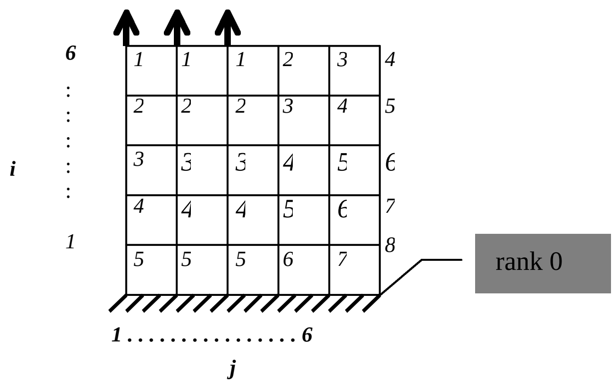


Figure 4 : point rank

The second adopted solution in order to optimize a calculus is based on the idea of scales swap. Our model simulates geometric scale of Fabric from geometric scale of Yarn. So, we proposed to do a temporal scale swap.

We need two sampling period : one for the fabric, one for the yarn. This is multi sampling. Then, sampling period Te is set for the fabric. It is the base of time to watch fabric deformation (mesoscopic scale). Sampling period te is set for the yarn. This is the time scale for watching mechanical wave propagation. Therefore, we have : Te > te. We choose (as shown on figure 5) to set : Te = N te, N is an integer.

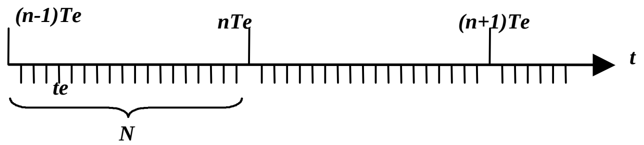


Figure 5 : multi sampling

Sum of stresses out of fabric structure are set constant for each sampling Te. Every sampling period te, there is an integration calculus in order to determine wave progression into yarn.

Observations of results show that the convergence calculus leads to structure dynamic balance with N' sampling period te less than N sampling period te : N' << N. So, we decided to swap to next sampling period Te as shown on figure 6.

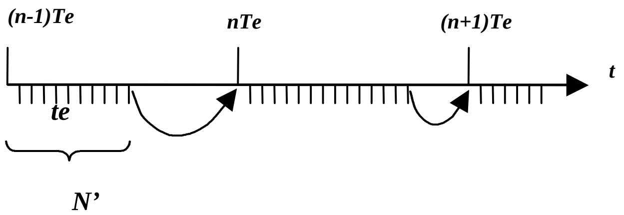
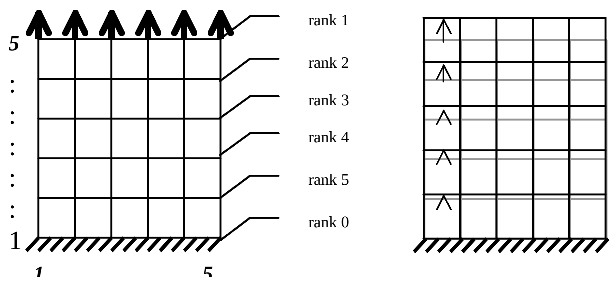


Figure 6: modified multi sampling

With such a solution, a convergence time of calculus is strongly decreased.

The third solution use estimation of move. We make the assumption that yarn have a homogenize elasticity. As shown on figure 7, such an assumption leads to predict crossing points moves. If points $N_{5,1}$ to $N_{5,5}$ have a move of X, then we do the prediction :

- points $N_{1,1}$ to $N_{1,5}$ move of ***1/5 X***,
- points $N_{2,1}$ to $N_{2,5}$ move of ***2/5 X***,
- points $N_{3,1}$ to $N_{3,5}$ move of ***3/5 X***,
- points $N_{4,1}$ to $N_{4,5}$ move of ***4/5 X***.



(a) before *(b) after*

Figure 7 : prédiction of point moves

As figure 8 shows, we apply the prediction to each period Te. The error of prediction is corrected by our calculation algorithm over the periods te

Such an approximation is very effective and it reduces the computation time enormously and it strongly contributes to deformation propagation in fabric structure. It is significant to note that the prediction assignement to fabric elementary points allows more quickly to reach the dynamic state of structure balance.

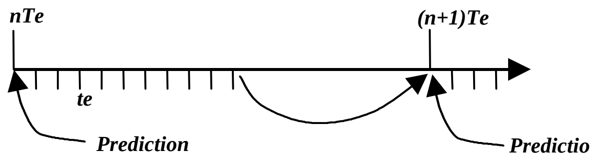


Figure 8 : Prediction application

Figure 9 compares convergences of one point towards three successive positions of balance in two cases. Case 1 is without prediction. Case 3 is with prediction.

On Figure 9, the third displacement was set voluntarily a little weaker than first two. This makes it possible to validate the adaptability of calculation technique. Whatever the prediction error, the algorithm enables the structure convergence towards balance dynamic position.

From ***t=0*** to ***t=Te***, the prediction allows to converge more quickly towards dynamic balance position of fabric structure in the case 2 than in the case 1. From ***t=Te*** to ***t=2Te*** case 2 avoids any calculation. The period of ***t=2Te*** to ***t=3Te*** makes it possible to see that case 3 corrects the prediction errors.

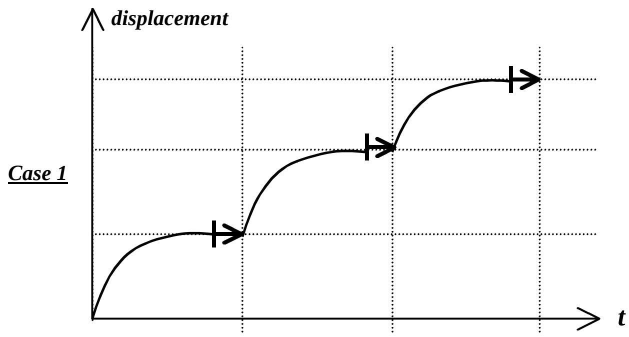


Figure 9 (a) : no prediction

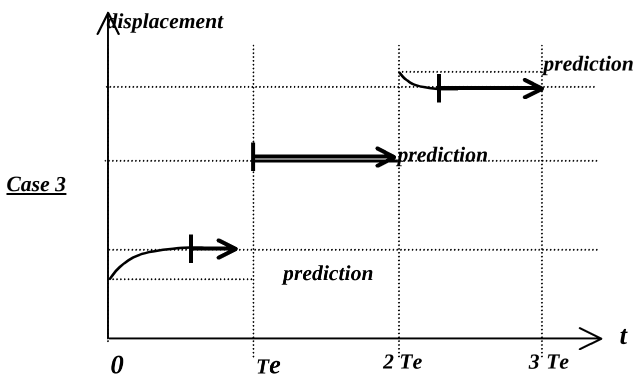


Figure 9 (b) : prediction

Moreover, simulation times of case 1 were divided by approximately 100 than in case 3.

SIMULATION

Traction test

In order to validate our model and our three solutions enabling the speed of computation increasing, at first we decide to simulate traction test. Virtually, we weave yarn to fabric. Then, stresses on warp yarn are applied on virtual fabric and Force (N) vs. Elongation (%) curves are saved.
The comparaison with reality is presented on Figure 10 tp point out differences between the model and expérimental results.

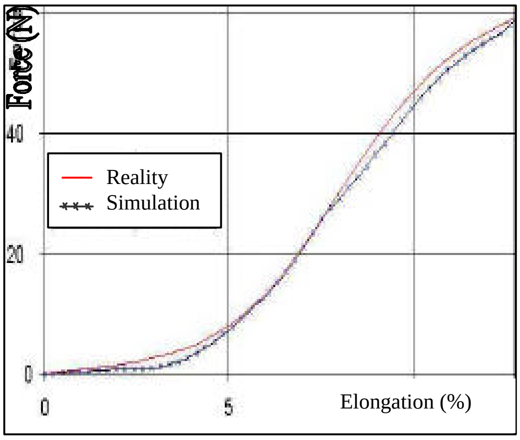


Figure 10 : traction test simulation and reality

The both curves are quite close compare for this phenomene. Therefore it is important to notice that the proposed computation speed increasing based on the convergence calculus optimization methods does not change the final results and that the proposed model is well adopted to such methods.

Pushing test

With such a quality of result, we do simulation of pushing test. Results are presneted on Figure 11. Three steps of fabric deformation is vizualized. Its seems very realistic, and takes only 3 days of calculus with one PC PENTIM II 400MHz. So, it is acceptable.

CONCLUSION

Our team developed a calculation algorithm to simulate fabric behavior.The proposed model is defined starting from fabric geometry, made up of a network of adapted springs, and mathematical equations giving it a mechanical character. As the fabric is considered as yarn assembly, this model is able to predict fabric mechanical properties starting from yarn mechanical properties.
Besides, convergence calculus optimization with our three methods strongly decrease the computation time and then allows us to make several simulation tests.

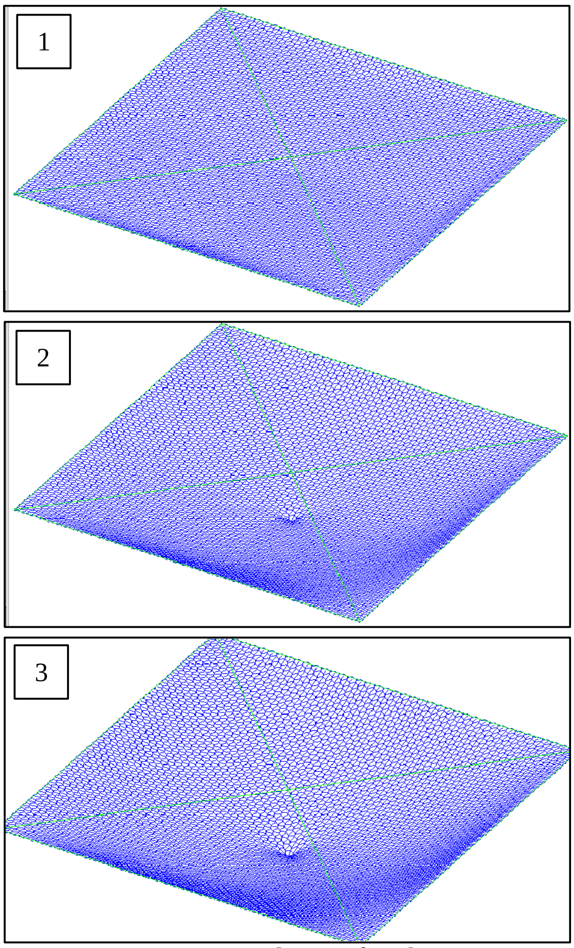


Figure 11 : Simulation of pushing test

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