Proposed Algorithm for Warp Direction Checking in Tensioned Fabric Structures

Hooi Min Yee¹, Kok Keong Choong²*

¹Senior Lecturer, Faculty of Civil Engineering, Universiti Teknologi MARA Pulau Pinang, 13500 Permatang Pauh, Pulau Pinang, Malaysia, minyh@ppinang.uitm.edu.my
²Associate Professor, School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia, cekkc@eng.usm.my
*Corresponding Author: cekkc@eng.usm.my

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Abstract. Mesh generation of tensioned fabric structure is needed before form-finding. The sequence of defining the mesh of a surface must ensure that the warp and fill direction of the fabric material used in the model is properly represented due to orthotropic nature of fabric material. Therefore, the checking of orientation of mesh is essential because the orientation of element nodes directly affects the direction of material axes. The manual checking of orientation of mesh is not sufficient to give the accurate and precise result and it is time-consuming. There is no such research to index and search for orientation of mesh specially. Procedure for changing node numbering sequence of elements in a mesh of FE model for initial assumed shape has been proposed in order to obtain a correct warp direction in elements. Results show that the proposed algorithm for warp direction checking can achieve substantially accurate classification.

Key words: Mesh, orthotropic, fill, orientation.

1. INTRODUCTION

Tensioned Fabric Structures (TFS) are structures that are composed of tensioned fabric as structural members. Fabric patterns are joined together at seams and are tensioned through mechanical means or cables to rigid supporting system to typically provide a roofing structure. Fig. 1 shows a sketch of a tensioned fabric structure.

Fig. 1: Basic components of a tensioned fabric structure

The materials used for membranes generally consist of a woven fabric coated with a polymeric resin. The two most commonly used membrane types are poly tetra fluoro ethylene (PTFE) coated plain weave glass-fibre fabrics and PVC coated plain weave nylon or polyester fabrics. A fabric is coated when a weather tight structure is required. In that case, as shown in Fig. 2, the fabric consists of three layers - one layer of woven yarns and two layers of coating materials. The coating protects the fabric from UV radiation degradation, rainwater and atmospheric moisture.

Fabric is made of woven yarns. Warp and fill yarns that are twisted together. The yarns are weaved in such a way that threads are perpendicular to one another and they are alternately passing over and under each other. As is given in Fig. 2, long straight yarns are called warp yarns and the direction parallel to the warp yarns are called warp direction; whereas perpendicular yarns are called fill yarns and they are weaved alternately over and under the warp yarns. The direction that is parallel to the fill yarns are called fill direction. Fig. 2 also shows the orthotropic nature of fabric materials.
Wang et al. (2010) have mentioned a number of well developed computer vision and image processing algorithm provide solid bases for automatic recognition of woven fabric patterns and automatic measurement of structural characteristics such as warp and fill counts in weaving technology. Kinnoshita et al. (1989), Wood (1990), Ravandi and Toriumi (1995), Xu (1996), Campbell and Murtagh (1998), Kang et al. (1999), Huang et al. (2000), Jeon et al. (2003), Rallo et al. (2003), Lachkar et al. (2003), Kuo et al. (2004), Lachkar et al. (2005), Kuo et al. (2005), and Kuo and Tsai (2006) have reported on the automatic analysis of woven textile structures. Wu et al. (2005) have developed a semi-automatic identification system of weave patterns for double-layer weft woven necktie fabric. Wang et al (2010) have developed automatic fabric analysis system by using inexpensive image processing techniques. Zheng et al (2009) have proposed a method to index and search weave patterns. Shinohara (2007, 2008, 2009, and 2011), Kondo et al (2000), and Shinohara et al (2004) have proposed for structure analysis of a textile fabric with its three-dimensional (3D) computed tomography (CT) image. It can be seen that no research studies focusing on the orientation of mesh before form-finding. In this paper, procedure for changing node numbering sequence of elements in a mesh of FE model for initial assumed shape has been proposed in order to obtain a correct warp direction in elements.

2. ALGORITHM FOR WARP DIRECTION CHECKING

Fig. 3a shows actual warp direction on fabric structure and desired warp direction as shown in Fig. 3b. The FE mesh obtained from software used for its generation may contain elements where warp directions are not properly represented as shown in Fig. 3c. Therefore, an algorithm for changing element node numbers to represent correct warp direction as shown in Fig. 3d has been proposed.
2.1. Reference Element

Fig. 3 shows an element in a FE mesh. One of the elements from the mesh representing the whole structure is chosen as a reference for the rest of elements for checking of warp direction. The direction of warp direction for the whole mesh is checked and changed if needed following the direction of the reference element.

The sequence of reading all elements is based on the three edges of each element which shares with the other three adjacent elements. Such sequence of reading is important for ensuring that all elements of the mesh representing the surface are read.

![Reference Element Diagram]

2.2. Rotation of Element

The surfaces of the TFS are curved as shown in Fig. 4a. In the proposed algorithm, surface elements are rotated to be parallel to each other for the purpose of checking warp direction of an element relative to the direction of the reference element. Such rotation is achieved by application of arbitrary rotation of axis. Fig. 4b shows rotation of arbitrary axis.

Algorithm for the rotation at any arbitrary axis has been given by Murray (2005). Eq. [1] shows the three dimensional function of ten variables for the rotation of the point \((x, y, z)\) about the line through \((a, b, c)\) parallel to \(\langle u, v, w \rangle\) by the angle \(\theta\).

\[
\begin{aligned}
&f(x, y, z, a, b, c, u, v, w, \theta) = \\
&\begin{bmatrix}
\frac{a(v^2 + w^2) + u(-bv + cw + vx + wy + wz) + ((x - a)(v^2 + w^2) + u(bv + cw - vy - wz)) \cos \theta + \sqrt{u^2 + v^2 + w^2(bv - cv - wy + vz) \sin \theta}}{u^2 + v^2 + w^2} \\
\frac{b(u^2 + w^2) + v(-au - cw + wx + vy + wz) + ((y - b)(u^2 + w^2) + v(au + cw - ux - wz)) \cos \theta + \sqrt{u^2 + v^2 + w^2(-aw + cu + wx - uc) \sin \theta}}{u^2 + v^2 + w^2} \\
\frac{c(u^2 + v^2) + w(-au - bv + ux + vy + wz) + ((z - c)(u^2 + v^2) + w(au + bv - vx - wy)) \cos \theta + \sqrt{u^2 + v^2 + w^2(aw - bu - vx + uy) \sin \theta}}{u^2 + v^2 + w^2}
\end{bmatrix}
\end{aligned}
\tag{1}
\]

The rotation at an arbitrary axis’s algorithm based on Eq. [1] is shown in Fig. 4b. Space is translated so that the rotation axis passes through the origin, space is rotated about the z-axis so that the rotation axis lies in the xz-plane, space is rotated about the y-axis so that the rotation axis lies along the z-axis, the desired rotation is performed by \(\theta\) about the z-axis and finally the inverse of step is applied.
Angle between two surfaces of elements is found by evaluating the tangent vector, which can be obtained by using orthogonal projection of a vector. \( \theta \) is the angle between surfaces of triangle ABD and. Both surfaces of triangles ABC and ABD are parallel to each other after rotation at 180° - \( \theta \).

3. APPLICABILITY OF PROPOSED ALGORITHM FOR WARP DIRECTION CHECKING

Proposed algorithm for warp direction checking has been written using MATLAB (2008). Element mesh with proper orientation of warp and fill direction is required in form-finding. An algorithm for checking warp direction of elements in FE mesh has been proposed in order to assign correct warp direction to all elements. A FE mesh of model with all its elements with correct warp direction assigned is shown in Fig. 5a. Fig. 5b and 5c show one example of incorrect warp direction of model. Such error is due to inappropriate choice of reference element. Fig. 5b and 5c show irregular mesh of triangular elements in the model from Fig. 5a. In order to assign correct warp direction to irregular mesh of triangular elements, as shown in Fig. 5b, a single element is chosen as the reference element for the whole of the mesh in part “a”. From Fig. 5c, a single element is chosen as the reference element for the whole of the mesh in part “b”.

In order to ensure that the proposed algorithm for checking the warp direction is applicable, node coordinates and number of elements node are taken from other FE software such as LUSAS (2006) and ANSYS (2004). The results of checking warp direction from the FE software obtained are correct as shown in Fig. 5a. The proposed algorithm for checking the warp direction is also applied in form-finding of TFS with surface shapes in the forms of minimal surfaces Catenoid, Helicoid, Scherk, Enneper, and complex or new forms such as Möbius strip and Costa. The proposed algorithm for warp direction checking show element mesh with proper orientation of warp and fill direction in form-finding for all minimal surfaces and complex forms. It also able to show an accurate orientation of warp and fill direction in form-finding for the highly curvature Costa TFS model as shown in Fig. 6.

4. CONCLUSION

The proposed algorithm for warp direction checking can achieve substantially orientation. Engineer can apply this method to check the warp direction of tensioned fabric structure. It sufficient to give the accurate and precise result and save a lot of times.
Fig. 5: (a) Correct warp direction of element for reinforced shade pavilion TFS model. The incorrect (b) warp direction at part “a”. (c) The incorrect of warp direction at part “b”.

Fig. 6: The correct sequence of warp direction of Costa TFS model.

REFERENCES

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Dr. Yee Hooi Min is a senior lecturer in Structural and Material Engineering Division, Faculty of Civil Engineering, Universiti Teknologi MARA Pulau Pinang. She is a member of Board of Engineers Malaysia (BEM), Institution of Engineers Malaysia (IEM), Construction Industry Development Board Malaysia (CIDB), and Concrete Society of Malaysia (CSM). Previously, she is a fellow, tutor and research officer in Universiti Sains Malaysia. Her area of specialization is computational mechanics and computational analysis of shell and spatial structures.

Dr. Choong Kok Keong is currently an associate professor at the School of Civil Engineering, Universiti Sains Malaysia. His area of specialization is computational analysis of shell and spatial structures.