IDENTIFICATION AND RESOLUTION OF INTERPENETRATION REGIONS OF WOVEN FIBER SURFACE MESHES USING DIFFERENT DATA REPRESENTATION TYPES

A Thesis Proposal

by

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ABSTRACT

As the usage of computational analysis for composite design becomes increasingly more popular, the desire to create and test textile composite materials is increasing as well. Previous research and study has been conducted using idealized woven textile geometries that lack the realism of imperfect woven composite fiber bundles (or tows). For most analyses, a filament (bundles of fibers) discretization of the tow is too complex to be analyzed, so instead, a surface representation of the tows is created so that homogenized properties can be applied. This representation is an approximation of the fiberized tow. When theses surfaces are created, small regions of interpenetrations are formed where the surfaces cross into each other. This creates two problems: a physically impossible occupation of the same space concerning the tows and incompatibility of the mesh resulting from these meshes crossing through each other.

This research proposal will outline a plan to address these problems and resolve them. The following three objectives are proposed rectify this issue: (1) Distinguish between data types that can be used to define the surface geometry, (2) Identify the regions of inter-penetrations between the surfaces, and (3) Discuss resolution to the interpenetration regions. The results of this study could result in more realistic woven textile geometries for computational testing of these complex composites that are compatible with traditional finite element analysis.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Dr. John Whitcomb and Dr. Darren Hartl of the Department of Aerospace Engineering and Dr. Terry Creasy of the Department of Materials Science and Engineering.

All other work conducted for the thesis was completed by the student independently.

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NOMENCLATURE

TAMU	Texas A&M University
VTMS	Virtual Textile Morphology Suite
SISL	Non-Uniform Rational B-Spline Library
NURBS	Non-Uniform Rational B-Splines
AFRL	Air Force Research Lab in Dayton, Ohio
FEA	Finite Element Analysis

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1. INTRODUCTION AND LITERATURE REVIEW

The growing use of fiber-matrix composite materials as both a decorative and functional material has also increased the need to better understand these materials in all of their forms. From unidirectional ply composites to intricate woven textile composites, the need for understanding material properties and mechanics for these composites has never been higher. In order to gain a more intimate understanding of the mechanical response for these composites, research turned towards computational models and simulations that were validated with experimental data. As these models became more accurate, understanding of both mechanical response and damage initiation increased. The use of computational models and analysis is now a fundamental aspect of most engineering and scientific research, and can been seen in use as far as early undergraduate studies.

1.1 Motivation

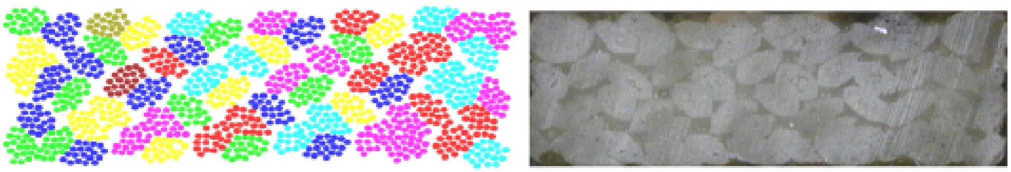
The motivation for this work comes from the desire to more correctly and realistically model fiber-matrix composite materials. Substantial experimental and computational research has been conducted on unidirectional ply composite as well as experimental research on textile woven composites. However, there is still a need for non-idealized textile composite geometries for computational analysis. The use of these geometries range from verification of computational models to insight into damage initiation and growth.

While there exists multiple software that can generate these geometries, the process (to be discussed later) can result is surface meshes of the geometries can be incompatible and have interpenetrations between them. A generalized solution to this issue could prove useful to future research in this area.

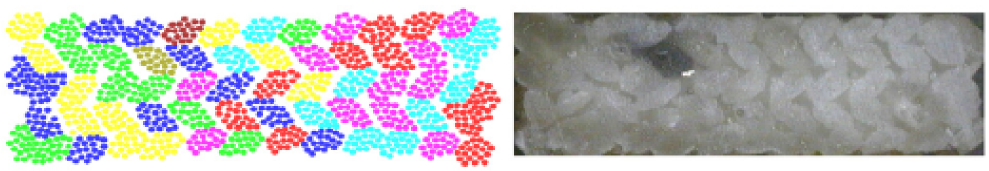
1.2 Woven Textile Composite Simulation

One method to creating more realistic woven geometries is to simulate the process that manufactures employ to create the fabrics [1]. The process begins by simulating bundles of fibers as "yarns". These yarns are made up of digital elements (cylindrical bars connected by friction-less pins) chained together. Each bar is given a stiffness in the longitudinal direction that amounts to a large value which eliminates yarn stretching. Then, a finite element style contact problem is solved where pins between two yarns can create contact forces between each other as well as friction forces. The result is realistic interactions between the digital chains. [1]

The result is fiber bundle cross sections that are similar to micro-CT scans from actual woven specimens, shown in Figure 1.1, from [1].



(a) Cross-section 1



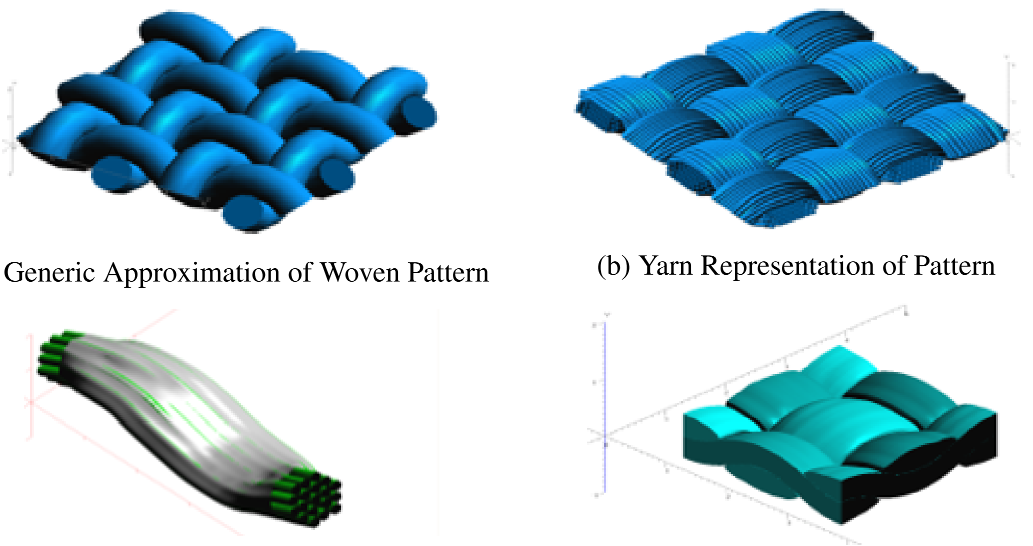
(b) Cross-section 2

Figure 1.1: Simulated (left (a) and (b)) vs. Actual Fiber Bundle Cross Sections

While there is possibly other software that can accomplish this level of similarity between simulation and reality, only two were explored. The first is Digital Fabric Mechanics Analyzer (DFMA) from Kansas State, overseen by Youqi Wang and students. The other is Virtual Textile Morphology Suite (VTMS), developed by Eric Zhou at AFRL. It should be noted that Eric Zhou is a former student of Youqi Wang and is cited in a previous paper [2].

It is from VTMS that the base geometry and surface mesh that is used in this study originates. Figure 1.2 shows the process visually. The surface inter-penetrations come as a result from the geometries shown in Figure 1.2.d).

The reasoning behind creating surface and volume approximations (Figure 1.2.c and d) is that the computational cost of analyzing many bundles that represent woven fibers is very high. Instead,



(a) Generic Approximation of Woven Pattern

(b) Yarn Representation of Pattern

(c) Surface Approximation of Yarn Bundles

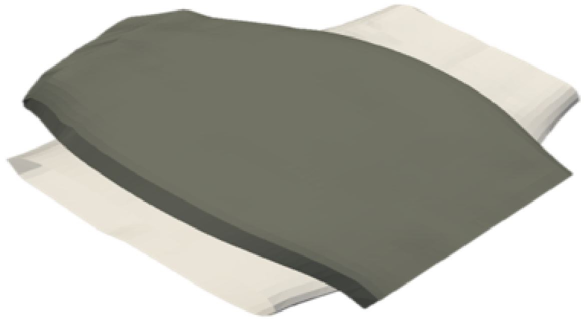
(d) Volume Model Derived from Surfaces

Figure 1.2: Evolution of Weave Textile Geometry

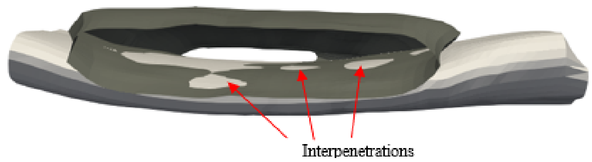
researchers currently are content with using a surface or volume approximation and applying material properties found in experiments.

1.3 Introduction to Interpenetration Regions

Once a surface representation is created, surfaces in close proximity have the ability to penetrate into each other, as shown in Figure 1.3. The arrows in Figure 1.3.b) indicate regions where one surface mesh is penetrating into the other. Physically, the two surfaces would come into contact and create some form of surface. This reaction is not represented here because the surfaces are created after the simulation process is done. These inter-penetrations represent the error in approximating the yarn bundles as a surface to apply homogenized properties to for analysis. Here in lies the focus of this study. Traditional finite element software requires that two geometries can not occupy the same space and must have compatible meshes along any boundaries that they may share. These regions must be fixed if a traditional FEA is to be conducted.



(a) Two Tow Surfaces in Close Proximity



(b) Through View of Penetrating Tows

Figure 1.3: Tow Surface Illustration and Penetrations

1.4 VTMS Surface Representation Types

VTMS has two distinct data types for its surface representations. They will be discussed below.

VTMS' Standard Tow Format

Once the yarn bundles are approximated as a surface, VTMS stores this surface as a standard tow format. Internally in the software, this data structure stores surface node coordinates and normals, along with stacks that define the cross-section of the surface along the tow path. Also internally stored are surface elements that connect surface nodes and are used for visualization purposes. However, once this data is exported to a file, only node location, node normal, and which stack the nodes belong to is stored. This effectively reduces the usefulness of the data when exported.

VTMS' Clipped Tow Format

Once the surface representations in VTMS are clipped to a desired dimension, the surface data is transformed into the clipped tow format. The clipped tow format is similar to many finite element mesh representations. When exported to a file, the data is organized into node location information, surface element type, and the connectivity of the surface elements by referencing node number. The file also stores the outward normal of each surface element. The internal representation of this data is similar to the exported representation and there is much less information lost when exported.

2. RESEARCH OBJECTIVES

To guide this study, three main goals were established to be completed during the duration of this research. These objectives will be discussed regarding both the result of completion and the foreseeable method. They are as follows:

1. Determine data representation types that will best describe the geometries from VTMS.
2. Implement methods for each representation type that will accurately identify interpenetration regions.
3. Discuss and implement methods that resolve inter-penetrations for each representation type.

2.1 Surface Representation Data Types

There are many types of computational analyses that can be used on computer models and geometries. Inherently, there are also many ways to describe this data. The first objective will be to explore possible representations of the data from VTMS and how they relate to the default types given from this software. This objective is a prerequisite to the remaining objectives as it is important to use the best suited data type for identifying and resolving inter-penetration regions between surfaces.

The origin software VTMS is written in C++ and it is the goal of this study to create a set of software that can implemented in not just VTMS but other software as well. Therefore, the methods developed will be written in C++. Completion of this objective will allow for a easy to use software that can translate the representation of the geometries in VTMS to other representation types.

2.2 Identification of Interpenetration Regions

The second objective will determine an accurate way to identify inter-penetration regions for the representation types chosen in the first objective. It is important that the detection algorithm correctly identify the regions inter-penetrating so that all incompatibilities may be fixed. The results of completing this objective will given all the information needed to correctly fix the inter-penetrations for the respective representation type for the geometries.

2.3 Resolution of Interpenetration Regions

The third objective is to identify a method that can resolve the issue of inter-penetrations for each representation type identified in the first objective. Once the method is identified, it will be implemented if possible or the required data to solve the inter-penetration will be given to the user. This will allow for multiple possible solutions to be implemented. It is conceivable that some solutions may be too complex to be implemented during this study.

3. Proposed Methods

The following chapter will discuss an approach to each of the previous discussed research objectives.

3.1 Surface Representation Data Types

Although the specific problem presented in this research may be fairly new, detecting collisions and conducting object intersection detection is not. Therefore, a review will be performed on current and antiquated techniques for solving these problems and the representation of the data that describes the objects being used in these methods. Two sources of inspiration that will be heavily explored is the video gaming industry and the computer-aided design (CAD) industry.

Many video games today have three dimensional worlds where the user can often run into and jump onto objects that occupy the world space. These video games conducting hundreds of collision detection tests a minute. Therefore, a study into how they represent the objects that can interact and how they detect these intersections will be conducted. It stands that any method used in this industry will be computationally efficient as collisions in many video game titles happen in fractions of a second.

Computer-aided design software (such as Auto Cad® and Solidworks®) have the ability to subtract volumes from each other and highlight intersection boundaries. They can do this very accurately for parts that must fit together with small tolerances. The method in which they both describe their parts and detect these intersections could be very influential in the surface representation type used in detecting and solving the inter-penetrations discussed in this research. A study into the theory of how these types of software are able to accurately describe these intersections will also be conducted.

An ideal data type to be used for identification and resolution of inter-penetrations will be directly related to the data either internally stored or exported from VTMS. Any data type chosen for the remaining objectives should not overly modify or approximate the data given from VTMS.

Ease of implementation and use of data types will also influence which representation types are explored. A representation that helps identify and resolve inter-penetrations accurately and in a timely manner is the goal of this objective.

A preliminary study into both of these areas revealed that most video games make use of a surface polygon mesh of objects. [3, 4]. CAD programs can use implicit and parametric representations of surfaces that make up the three dimensional objects that can collide [5].

3.2 Identification of Interpenetration Regions

The exact method for accurately identifying inter-penetrating regions between surface representations will depend on the chosen representation types. From the preliminary study mentioned previously, one representation type is a polygon surface description that has use in the video game industry. In [3, 4], different methods for avoiding and identifying inter-penetrations are discussed. Some of these ideas may be adapted for the purposes of this research.

Another potential type of representation of the tow surfaces is an analytical surface. Rather, a surface that can be defined by a single or set of equations. This readily seen in CAD software design [5]. In these types of software, there are algorithms that are used to define where two bodies intersect. These algorithms also may be adapted for the needs of this study.

3.3 Resolution of Interpenetration Regions

Similar to the detection of inter-penetrations, the resolution of inter-penetrations will also depend on the representation type used to describe the tow surfaces. The representations discovered thus far have been accompanied with a standard form of a solution. Therefore, the process of solving the inter-penetrations will conceivably consist of methods adapted from the standard solution form. In each case of representation type, the solution will be adapted and implemented for this research.

4. EXPECTED RESULTS

The following are the expected results for each objective of this research.

4.1 Surface Representation Data Types

Multiple types of representation are expected to be found during this objective. The purpose of this objective is to identify ideal representation types that will aid in fulfilling the remaining objectives.

The results from this objective are expected to be:

- One or more surface representation types that can be used to describe the data from VTMS
- Insight into conventions of multiple industries that use penetration and collision detection algorithms
- Inspiration on multiple types of identification and resolution methods

4.2 Identification of Interpenetration Regions

Properly identifying the inter-penetration regions of the surface representations is vital to completing the third object of this research. Without proper identification, there can not be a complete resolution of the inter-penetration regions.

The results from this objective are expected to be:

- An algorithm that accurately detects inter-penetration regions for multiple representation types
- An algorithm that collects the required data to resolve inter-penetrations
- A methodology to accurately visualize interpenetration regions

4.3 Resolution of Interpenetration Regions

Completion of this research is synonymous with resolving inter-penetrations or determining the remaining steps for the most realistic solution. The best solution to resolving these inter-penetrations may vary depending on the situation.

The results from this objective are expected to be:

- An algorithm that resolves inter-penetrations for one or more of the chosen representation types
- Recommendations for the usage of algorithms and methods developed during this research
- A method that exports useful inter-penetration data for user discretion
- A suite of software that can be easily implemented for other users

5. RESEARCH PLAN

5.1 Time-line

Below is a time-line that breaks down each object into work done by each academic semester.

Table 5.1: Research Timeline By Semester

Objective	Spring 2017	Fall 2017	Spring 2018
Surface Representation Data Types	Literature Review and Determination of Data Types		
Identification of Interpenetration Region	Literature Review and Discovery of Methods	Implementation of Methods	Use of Methods
Resolution of Interpenetration Region		Literature Review and Planning of Methods	Implementation and Verification of Methods

5.2 Resources and Equipment

This research is entirely digital and requires no physical equipment apart from a computer. The software will be developed in C++ which requires a compiler and editing software. It is also likely that external software libraries not developed by the student and will be noted.

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