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学位論文題目	A Study on the Mathematical Modeling-Based Digitization of Mongolian Traditional Patterns （数理モデルに基づくモンゴル伝統文様のデジタル化に関する研究）
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学位論文内容の要旨

Preserving culturally significant artifacts is essential for safeguarding a civilization's heritage and identity. Mongolian traditional motifs and patterns, deeply rooted in nomadic culture, reflect strong connections to nature, geometry, animals, plants, and symbolic forms. These intricate designs are widely found in traditional clothing, architecture, furniture, and everyday objects such as carpets, saddles, and tools. However, despite their cultural importance, systematic studies focusing on the mathematical digitization of Mongolian patterns remain limited.

This thesis proposes a mathematical modeling-based framework for the analysis, digitization, and reconstruction of Mongolian traditional motifs and patterns. Accordingly, this study focuses on the systematic analysis and digitization of Mongolian patterns through a mathematical modeling-based approach. A classification method is developed to categorize representative motifs into five groups: geometric, plant-based, animal-inspired, symbolic, and nature-related patterns. Based on this classification, six representative Mongolian artifacts are analyzed in terms of motif composition, symmetry, and geometric complexity, distinguishing between symmetric and asymmetric structures.

To enable accurate digital preservation, a computational framework is proposed for the geometric modeling of motifs. The approach employs explicit mathematical formulations combined with fundamental geometric entities, including circles, circular arcs, logarithmic spirals, and astroids. These elements are integrated using geometric transformations such as translation, rotation, reflection, and scaling, allowing the reconstruction of complex patterns while maintaining symmetry and compositional consistency.

Two case studies are conducted to verify the proposed framework. In the first case study, a traditional Mongolian snuff bottle pouch (daalin) pattern is digitized by decomposing the original design into multiple geometric components. Several parameter experiments are performed to determine suitable geometric conditions for stable pattern generation and smooth curve connectivity. In the second case study, a heart-shaped motif is reconstructed using logarithmic spirals and straight-line segments, demonstrating the applicability of the proposed method to patterns with different geometric characteristics.

After geometric modeling, the generated patterns are converted into vector-based representations and imported into OpenSCAD (version 2021.01) for CAD model generation. Direct SVG conversion from original images and manual tracing using SolidWorks are also tested for comparison. The results show that the proposed mathematical modeling approach provides more stable geometry, smoother curve connectivity, and improved controllability compared with the other approaches. Physical prototypes are fabricated using a GUTENBERG G-ZERO L1 fused filament fabrication (FFF) 3D printer with PLA material, establishing a complete digital to-physical workflow.

This approach not only facilitates the preservation and dissemination of Mongolian cultural heritage but also supports applications in education, museum exhibitions, and digital archiving. In addition, culturally inspired products and souvenirs derived from these digital models possess both artistic and commercial value. As the number of skilled artisans continues to decline, the integration of mathematical modeling and digital manufacturing technologies provides a practical solution for preserving traditional knowledge while enabling scalable and precise reproduction of culturally significant patterns.

審査結果の要旨

本学位論文では，モンゴル伝統文様の保存および再現を目的として，数学的モデリングに基づくデジタル化手法を考案した．まず，代表的な文様を幾何学的文様，植物文様，動物文様，象徴文様および自然文様の 5 種類に分類し，それらの構成，対称性および幾何学的複雑性を解析した．次に，円，円弧，対数らせん，アステロイドおよび直線等の基本的な幾何要素を，平行移動，回転，鏡映ならびに拡大・縮小等の幾何変換によって組み合わせることにより，複雑な文様を数学的に再構成した．考案した手法の有効性を検証するため，モンゴルの伝統的な嗅ぎたばこ入れ用ポーチ（ダーリン）の文様およびハート形文様を対象として，二つのケーススタディを実施した．再構成した文様をベクトル形式に変換した後，スクリプト言語に基づく CAD システムを用いて CAD モデルを生成し，FFF 方式の 3D プリンタにより造形した．比較検証の結果，考案した手法は，原画像のベクトルグラフィックスへの直接変換および手作業によるトレースと比較して，幾何形状の安定性，曲線接続の滑らかさおよび形状パラメータの制御性に優れていることが確認された．これにより，伝統工芸品に含まれる文様の分類，幾何要素への分解，数学的再構成，ベクトル化，CAD モデル化および 3D 造形に至る一連のデジタル・フィジカル化プロセスを構築した．考案した手法は，モンゴル伝統文様の保存，デジタルアーカイブ化，教育および博物館展示に寄与するとともに，文化的意匠を活用した製品や土産品の設計・製造にも応用可能である．さらに，熟練職人が減少する中，伝統的知識を継承し，文化的価値を有する文様を高精度かつ効率的に再現するための実用的な手段となることが期待される．これらの研究成果は，Mathematical and Computational Applications をはじめとする国際的に評価の高い学術誌ならびに国内外の学術会議において発表されている． よって，提出された学位論文の内容および該当する学術論文の質等を総合的に考慮した結果，申請者は北見工業大学博士（工学）の学位を授与される資格を有する者であると認める．