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学位論文内容の要旨

Reverse engineering mimics critical features of a given object and creates its accurate (or enhanced) virtual model (digital model) and replica (physical model). It is often used to digitize existing objects in different engineering fields and preserve culturally significant artifacts. In conventional reverse engineering, a 3D scanner scans the exposed surfaces of a given object, which results in a relatively large point cloud. The point cloud is cleaned of noise and outliers before the surfaces are reconstructed. The reconstructed surfaces undergo geometric modeling, which results in a digital model of the object. This kind of reverse engineering requires sophisticated devices (a 3D scanner), a 3D CAD system, and complex computations. It is challenging to make a reverse engineering process less dependent on sophisticated devices and complex computations. This study overcomes this challenge by developing a novel reverse engineering method. The proposed method uses an analytical approach to create a noise- and outlier-free point cloud of a given object. The analytical approach is based on a recursive process that requires two types of input. The first type of input consists of two parameters denoted as instantaneous distance and instantaneous angle. These parameters vary in each iteration of the recursive process. The other input consists of three parameters: center point, initial distance, and initial angle. They remain constant for all iterations. The proposed approach produces a small point cloud to model some features of a given object, even when the mathematical representations are unknown. In this case, the instantaneous angle can be increased linearly after each iteration, and the instantaneous distance can be varied using simple and well-known mathematical functions. The modeling ability of the proposed approach is validated by comparing two point clouds of the same shape. The first point cloud is created using the parametric equation for a given shape (e.g., circle, ellipse, spiral, astroid, and straight lines). The other point cloud of the same shape is created using the proposed approach.

Culturally significant artifacts can be digitized using the proposed reverse engineering method. This study considers the problem of reverse engineering some patterns belonging to the Ainu, the indigenous people of Hokkaido. They use fourteen elementary motifs (e.g., "Ayus," "Morew," "Sik," and "Utasa") to create unique patterns with which they decorate their houses, clothing, ornaments, utensils, and spiritual goods. The mathematical representations of these motifs and the underlying patterns are unavailable. The proposed approach is applied to create point clouds representing some selected Ainu motifs. For each point cloud, the instantaneous angle is increased linearly, and the instantaneous distance is adjusted as needed using some simple mathematical functions. This way, a database of Ainu motifs is prepared. Some point clouds are exported to a commercially available CAD system. After simple geometric modeling (rotation, translation, extrusion, and copying), the point clouds are transformed into digital models (virtual models) of the respective motifs and patterns. The digital models are used to manufacture replicas of the respective motifs/patterns with an ordinary 3D printer. This way, this study digitally preserves the craftsmanship of Ainu motifs and patterns. The proposed approach equally applies to artifacts other than Ainu motifs. This is demonstrated by producing a virtual model and replica of an ancient ewer (which is a 3D shape). The processes involved in the proposed reverse engineering (point cloud creation using an analytical approach, 3D CAD system-based geometric modeling of the point cloud to create a digital model, and replica manufacturing using a 3D printer) do not require sophisticated devices. They are free from heavy computations, unlike conventional reverse engineering processes. Nevertheless, the thesis is organized into seven chapters. The first chapter presents the background, scope, and objectives of this study. The second chapter provides a literature review for reverse engineering and its application to 3D printing. The third chapter describes the abovementioned reverse engineering method. The fourth chapter details the proposed reverse engineering method's application while creating a virtual/physical prototype of Auni motifs/patterns and other cultural artifacts. The fifth chapter discusses the implications of this study and highlights future work. The final chapter concludes this thesis.

論文審査結果の要旨

本論文では，三次元プリンティングに適した新リバースエンジニアリング手法の開発とその文化遺産保存への応用について研究し，有用な知見が示されている．特に，ある平面に点群を発生する手法を考案した．考案した手法により様々な形状の点群化が可能になった．その結果，北海道アイヌに該当する１４種類の基本模様の点群モデルを構築することに成功した．更に，基本模様の点群モデルを合成し，複雑な模様の点群モデルも構築することに成功した．また，各点群モデルを市販のCADシステムに入力し，模様の仮想モデルを構築した．そして，デジタル化した仮想モデルのレプリカを三次元プリンターで正確に作製することに成功した．こういう成果は，様々な文化遺産のデジタル化による保存を可能とする．本論文で述べたリバースエンジニアリング手法にはスキャナや複雑な幾何学的計算等は必要ないため，設備等のコスト削減に有効であり，産業的に大変有用である．

よって，提出された学位論文の内容及び該当する学術論文の質等を考慮し，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が有る者と認める．