Reversible Watermarking of NURBS-Based CAD Models

Wolfgang Funk

Fraunhofer Institute for Computer Graphics Research IGD, Fraunhoferstr. 5,
64283 Darmstadt, Germany
wolfgang.funk@igd.fraunhofer.de
http://www.igd.fhg.de

Abstract. We present an algorithm for embedding robust reversible watermarks into CAD models that are represented by a collection of NURBS (Non Uniform Rational B-Spline) surface patches.

Changes to the geometry of the surface representation are introduced by moving one control point per surface patch. This approach provides robustness against converting the model into the mesh representation. The information needed to restore the original control point location is added to the knot vectors of the patch, thus enabling recovery of the original model from the watermarked NURBS representation.

We exploit the properties of the NURBS representation for preserving the continuity between adjacent patches. Continuity is the major criterion of designers for assessing the quality of surface models.

1 Introduction

The algorithm presented in this paper was designed to support a scenario that we refer to as *engineering scenario*. It deals with valuable 3D data that are created by highly skilled specialists in CAD-based production chains. Automobiles, ships, aircrafts and trains are examples for such models. Usually, a single digital master model is produced, which is the basis for tool creation and the reference for control measurements during production. In contrast to models designed for applications such as games or web sites with 3D support, high quality CAD surface models are represented as sets of parametric curves and surface patches, which are mathematically described by Non-Uniform Rational B-Splines (NURBS).

In general, the meaning of design information contained in a high quality CAD model is twofold: the functionality, i.e. the technical know-how and innovation represented by the model, and the aesthetic aspect of its shape. In the latter scenario, even slight modifications of the model may not be acceptable when the free form surface represented by the model must be reprocessed or is actually manufactured, e.g. by a milling machine. To cope with this restriction, the modification of the model introduced by the watermark must be reversible so that the master model can be restored.

J. Camenisch et al. (Eds.): IH 2006, LNCS 4437, pp. 172–187, 2007.

We present a watermarking scheme that preserves the important properties of the shape, in particular the continuity at the boundaries of surface patches. The watermark can be detected and reversed without reference to the original in the NURBS representation of the model. It can be verified in versions of the model that have been transformed into a polygonal mesh. The polygonization of NURBS surfaces is usually denoted as *tesselation*. Here, verification means that we can decide if a given watermark was embedded: this approach is often referred to as zero-bit or one-bit watermark in the literature; we prefer the term *one-bit watermark* in this paper. The security of our reversible watermarking scheme relies on knowledge about the locations of specific points that define the geometry of the NURBS surface, the *control points*, as well as the location of specific points in the parameter space of the surface, the *knots*.

The paper is organized as follows. In Sect. 2 we give a very short review of NURBS-based CAD models and the concept of trimmed surfaces. In Sect. 3 we state the problem and briefly describe the requirements of the engineering scenario. Section 4 reviews previous work on digital watermarking for models in parametric representation and puts our approach in context. Section 5 presents an overview of our watermarking scheme. Section 6 gives a detailed description of the embedding algorithm as well as the retrieval and reversal algorithm that operates on the NURBS representation. Section 7 details how we cope with preserving continuity between adjacent surface patches. In Sect. 8 we give a short description of verifying a watermark in tesselated versions of the model. Finally, we draw conclusions and look beyond the current status to questions not answered so far.

The algorithm presented in Sect. 6 operates on a single surface patch to embed or retrieve one information bit. In order to handle a complete watermark message, a framework for accessing and processing all patches of the model is required. A complete discussion of the framework is out of the scope of this paper, thus, in Sect. 7 we elaborate on the framework component that preserves continuity conditions. Some aspects of retrieving a complete watermark message are discussed in Sect. 8.

2 NURBS-Based CAD Models

In contrast to polygonal meshes, NURBS-based models are exact mathematical descriptions of the surface of objects. In general, a NURBS-based surface model is composed of NURBS curves and surface patches. Here we give a very short review of the definitions in the notation used by Piegl and Tiller [1].

A NURBS curve $\mathbf{C}(u)$ is a piecewise polynomial curve defined by control points $\{\mathbf{P}_i\}$ that form a control polygon, the weights $\{w_i\}$, and the pth degree B-Spline basis functions $\{N_{i,p}(u)\}$ defined on the nonperiodic and nonuniform *knot vector* $U = (u_0, ..., u_m)$. The knot vector represents the parameter values of the endpoints of the segments of the curve, the knots, and is a nondecreasing sequence of real numbers. A NURBS curve $\mathbf{C}(u)$ is given by