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Information technology — Computer graphics, image processing and environmental data representation — Material property and parameter representation for model-based haptic simulation of objects in virtual, mixed and augmented reality (VR/MAR)

Technologies de l'information — Infographie, traitement d'images et représentation des données environnementales — Propriété matérielle et représentation des paramètres pour la simulation haptique basée sur un modèle d'objets en réalité virtuelle, mixte et augmentée

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Contents

Page

Foreword

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 24, *Computer graphics, image processing and environmental data representation*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

Introduction

Both virtual reality (VR) and mixed and augmented reality (MAR) employ virtual, synthetic and computer-generated objects in their respective scenes, and they are rendered not only visually but in other modalities in order to provide rich user experience based on realism, presence and augmentation.

VR and MAR applications are increasingly using haptic feedback to allow the user to interact physically with the virtual or real objects and provide higher realism and elevated experience. That is, the input from and output to the user may be delivered kinaesthetically (i.e. force feedback) through physical simulation and the resulting force rendered through mechanical haptic devices. Note that the interacting virtual or real object may be situated in virtual reality (VR), augmented reality (AR) and augmented virtuality (AVR) – namely, across all types of MAR.

A correct and effective rendering of forces requires the relevant physical description of the materials of the objects involved in the physical interaction and simulation. In addition, depending on the needs of the application, different haptic rendering algorithms may be employed. Conventional standards for virtual and mixed reality have lacked constructs for expressing such material properties or algorithmic details and thereby supporting a comprehensive, faithful and flexible haptic rendering. For example, most current standard 3D graphic or virtual object representations can only describe material properties for visual rendering (e.g. for lighting effects and shading).

This document also provides definitions for terms related to material properties and physical simulation in the context of the haptic rendering and its algorithms.

The target audience of this document are mainly VR and MAR system developers and content designers interested in specifying and using haptic interaction. This document provides a basis for application standards for any VR and MAR applications and content representation that uses haptic modality for input and output.

However, this document establishes the information model. It does not promote or propose to use a specific language, file format, algorithm, device, implementation method or standard. The model is intended to be considered as the minimal basic model that can be extended for other purposes in actual implementation.

The content of this document is derived from ISO/IEC 18039, which, among other things, specifies the possible inclusion of haptic feedback (and associated devices) in experiential VR and MAR contents (and systems). The specification can be one important component in ISO/IEC 3721-1[1)], whose purpose is to lay out and specify the information model for various essential MAR content components and their relationships. While ISO/IEC 3721-1 lays the foundation and overall framework, it does not go into all the details (e.g. material or haptic properties of an object). As haptic feedback may be used in purely virtual environments as well, this document also relates to ISO/IEC 19775-1.

1) Under preparation. Stage at the time of publication: ISO/IEC DIS 3721-1:2021.

Information technology — Computer graphics, image processing and environmental data representation — Material property and parameter representation for model-based haptic simulation of objects in virtual, mixed and augmented reality (VR/MAR)

1 Scope

This document specifies:

— physical and material parameters of virtual or real objects expressed to support comprehensive haptic rendering methods, such as stiffness, friction and micro-textures;

— a flexible specification of the haptic rendering algorithm itself.

It supplements other standards that describe scene or content description and information models for virtual and mixed reality, such as ISO/IEC 19775 and ISO/IEC 3721-1.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
dynamic friction
friction that changes dynamically under certain external conditions

3.1.2
friction
tangential force emanating from the contact between two objects

3.1.3
haptic
kinaesthetic, force feedback and tactile feedback

3.1.4
haptic device
apparatus that delivers computer-simulated forces and torque to a human user for sensation, and also receives input in the form of force and torque to be conveyed to the computer simulation of virtual and mixed reality environment for emulating physical interaction

3.1.5
haptic modality
modality synonymous to the haptic sensation

3.1.6
haptic rendering
computing the amount of forces and torques occurring at the interaction point, based on the physical simulation and interaction of the virtual and mixed reality world, and reflecting them to the user through the haptic device

3.1.7
physical interaction
interaction, real or virtual, between a user and object(s) that involves the use of forces and torques via contact

3.1.8
physical simulation
simulating the dynamic physical phenomena in the virtual and mixed reality environment based on the environment description and given physical laws, and in the process, computing the relevant parameter values, such as the amount of forces and torques

3.1.9
stiffness
rigidity of an object and the extent to which the object resists deformation in response to an applied force

3.1.10
surface texture
micro surface texture
micro-scaled protrusion pattern on the surface of an object

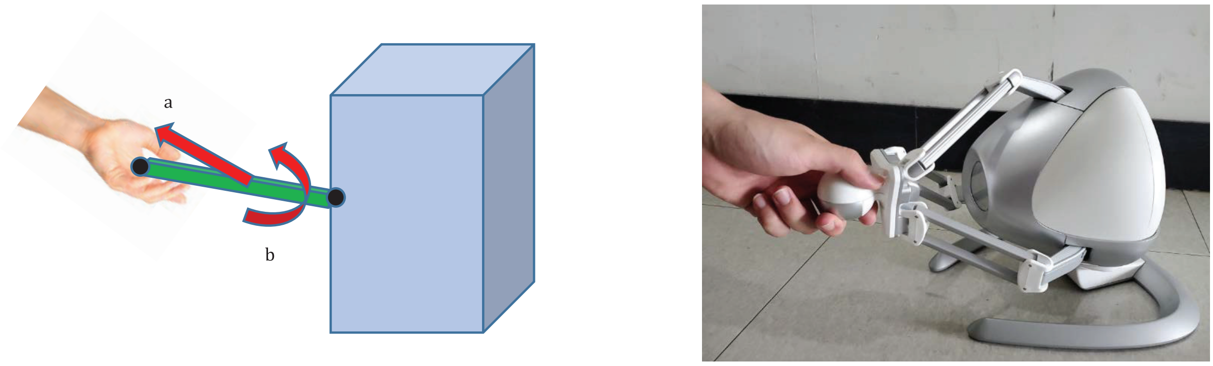
3.2 Abbreviated terms

AR	augmented reality
FFT	fast Fourier transform
MAR	mixed and augmented reality
VR	virtual reality

4 Overview: Material properties for haptic simulation

4.1 General

Haptic rendering in the context of VR or MAR simulation refers to computing for the proper force or torque to be exerted by the haptic device at a given point in the VR or MAR space (e.g. magnitude and direction), see Figure 1.



a Force.

b Torque.

Figure 1 — Physical interaction with a virtual or real object (left) and using the haptic device to obtain kinaesthetic feedback (right)

H3D API is an open-source, cross-platform, scene graph AI that has extended the X3D material and surface node[3] as “SmoothSurface,” “FrictionalSurface,” “DepthMapSurface” and “HapticTextureMap” to express various haptic parameters directly.

For example, the declaration:

<SmoothSurface stiffness="1,0" damping="0,5"/>

includes the linear stiffness of 1,0 and the damping factor of 0,5 for computing the resulting force as in Formula (1):

$$F = kx + vx' \tag{1}$$

where

x is the object displacement;

k is the stiffness factor;

v is the damping factor.

The following declaration is used for representing a “frictional” surface with added parameters such as the static and dynamic friction constants. Consequently, the resulting force is computed differently from Formula (1) with these added parameters.

<FrictionalSurface stiffness="1,0" damping="0,5" staticFriction="0,61" dynamicFriction="0,4"/>

This approach is simple and effective, and can be used as a quick fix for the absence of any haptic material properties to begin within X3D or other similar simulation content representation. But it is also ad hoc in that different types of surfaces are defined with the surface-specific parameter sets. This in turn makes the flexible specification of the haptic rendering algorithm difficult. Haptic rendering is associated with the physical simulation of virtual or real objects which can be carried out at different degrees of accuracy and complexity, and also the mechanical characteristics of the haptic device used and the available computing resource. This makes the haptic rendering to employ a particular model or algorithm. At any rate, usual physical simulation generally computes for the gross amount of forces and torques arising at object contact points and moments. The most basic physical simulation and haptic output requires various parameters, the three basic ones being i) stiffness, ii) friction and iii) surface texture information, which are all material properties of the interacting objects.

4.2 Stiffness

Stiffness (see Figure 2) refers to the rigidity of an object. It describes the extent to which the object resists deformation in response to an applied force. In haptic rendering, stiffness should ideally be given differently at the surfaces or vertices of the object. In large and slow deformation, stiffness may be non-constant. Stiffness is measured in newtons per meter.

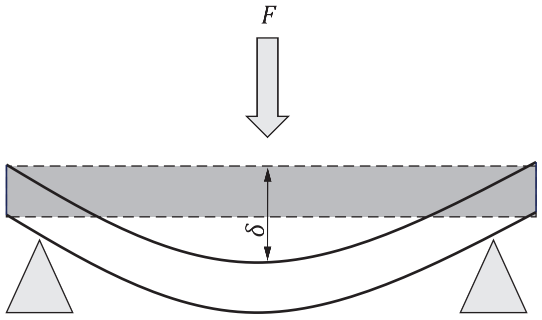


Figure 2 — An object deformed by δ from external force, F

Stiffness may be computed from other related object or material parameters, especially to model its time-dependent dynamics. For instance, Formula (2) shows the non-linear Hunt-Crossley model equation[4] that describes the elastic object deformation (i.e. x represents the object or surface displacement) and associated force (f) using three parameters: K (spring constant), B (damping coefficient) and m (object- or material-specific constant that is typically between 1 and 2). The three parameters in essence indirectly represent the object or material stiffness (ε is an arbitrary error term).

$$f = Kx^m(t) + Bx^m(t) + x'(t) + \varepsilon \quad (2)$$

where

- f is the associated force;
- K is the spring constant;
- x is the object or surface displacement;
- m is the object- or material-specific constant;
- B is the damping coefficient;
- ε is an arbitrary error term.

4.3 Friction

Friction refers to the tangential force emanating from the contact between two objects and responsible for producing high-frequency contact response. It is the source of the force that resists the relative motion of two objects in contact (see Figure 3).