

团 体 标 准

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信息技术 虚拟现实内容表达 音频

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前 言

本文件按照GB/T 1.1—2020《标准工作导则 第1部分：标准文件的结构和起草规则》的规定起草。

请注意本文本的某些内容可能涉及专利，本文件的发布机构不承担识别这些专利的责任。

本文件由数字音视频编解码技术标准工作组提出。

本文件由中关村视听产业技术创新联盟归口。

本部分起草单位：清华大学、北京理工大学、中国电子技术标准化研究院、北京字跳网络技术有限公司、赛因芯微(北京)电子科技有限公司、北京全景声信息科技有限公司、中关村视听产业技术创新联盟、清华大学天津电子信息研究院、北京大学、咪咕文化科技有限公司、腾讯科技(深圳)有限公司、北京爱奇艺科技有限公司、小米通讯技术有限公司、全景声(北京)智能科技有限公司、华为技术有限公司、中国传媒大学等。

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引 言

随着虚拟现实（VR）技术的不断涌现，虚拟现实已成为增强沉浸感的新兴媒体形式，VR 音频内容表达与渲染重建技术在虚拟现实沉浸感、真实感体验中占有重要地位。目前虚拟现实全景视频技术已经受到广泛关注和重视，但是由于缺乏 VR 音频内容表达和渲染重建的技术规范，难以实现各种 VR 音频采集制作与终端回放设备或系统间的互通共享。本标准在遵循 ITU-R BS.2076-2 规范的前提下，面向适应我国全景音频播出、沉浸式音频通信、虚拟现实音频交互等领域，提供虚拟现实音频内容的元素定义、编码规范和渲染重建建议，服务于虚拟现实（VR/AR/MR/XR）设备和相关系统中的音频应用。本文件旨在确立 VR 音频元数据模型和渲染系统之间的协同关系，以及 VR 音频元数据流与音频流之间的可能的复接模式，形成 VR 音频内容表达的互联互通应用规范，支持 3DoF 和 6DoF 等虚拟现实场景下，涉及基于声道、对象、场景三类信号的采集制作和渲染重建。本标准设计了音频元数据模型、音频编解码系统和 VR 音频渲染系统之间的解耦合架构，三个系统之间既相互独立，又紧密配合，形成 VR 音频内容表达的应用规范。本标准将对 VR 音频坐标系、元数据模型、渲染器系统、AVS 音频元数据串行流封装格式进行规范。

本文件的发布机构提请注意，声明符合本文件时，可能涉及到如下 52 项专利的使用。其中，可能涉及到第 6、7、9、10 章及附录相关的专利名称如下：

PCT/CN2021/100076，音频渲染系统、方法和电子设备；PCT/CN2022/098882，音频渲染系统、方法和电子设备；PCT/CN2021/100062，用于音频渲染的音频信号编码方法、装置和电子设备；PCT/CN2022/098850，音频渲染系统、方法和电子设备；PCT/CN2021/114366，一种 3D 音频元数据系统；PCT/CN2022/114219，音频信号的处理方法和装置；PCT/CN2021/121135，声音路径能量的淡入淡出方法、电子设备和介质；PCT/CN2022/122204，音频渲染方法、音频渲染设备和电子设备；PCT/CN2021/121718，一种动态估计场景近似长方体房间的方法；PCT/CN2022/122635，一种音频渲染系统和方法；PCT/CN2021/104309，混响时长的估计方法、音频信号的渲染方法和电子设备；PCT/CN2022/103312，音频信号的渲染方法、装置和电子设备；PCT/CN2021/115130，用于音频渲染的信号处理方法、装置和电子设备；PCT/CN2022/115194，用于音频渲染的信号处理方法、装置和电子设备；PCT/CN2021/121729，用于空间音频渲染的系统、方法和电子设备；PCT/CN2022/122657，用于空间音频渲染的系统、方法和电子设备；202110984837.4，一种音频制作模型和生成方法、电子设备及存储介质；202111102045.6，音频节目元数据和产生方法、电子设备及存储介质；202111100818.7，音频内容元数据和产生方法、电子设备及存储介质；202111102038.6，音频对象元数据和产生方法、电子设备及存储介质；202111205630.9，音轨唯一标识元数据和生成方法、电子设备及存储介质；202111204386.4，一种音频轨道元数据和生成方法、电子设备及存储介质；202111202898.7，一种音频流元数据和生成方法、电子设备及存储介质；202111308422.1，基于音床音频包格式元数据和产生方法、设备及介质；202111308430.6，基于对象音频包格式元数据和产生方法、设备及介质；202111306844.5，基于场景音频包格式元数据和产生方法、设备及存储介质；202111308421.7，基于双耳音频包格式元数据和产生方法、设备及介质；202111021068.4，基于音床音频通道元数据和生成方法、设备及存储介

质; 202111020417.0, 基于对象音频通道元数据和生成方法、设备及存储介质; 202111021066.5, 基于场景音频通道元数据和生成方法、设备及存储介质; 202111021039.8, 基于双耳音频通道元数据和生成方法、设备及存储介质; 202111666346.1, 一种广播音频格式文件生成方法、装置、设备及存储介质; 202111666362.0, 音频元数据区块的生成方法、装置、设备及存储介质; 202210588174.9, 生成渲染器内部数据结构的方法、装置、设备及存储介质; 202210634563.0, 利用元数据对基于音床的音频进行渲染的方法及装置; 202210762912.7, 共享渲染器组件的配置方法、装置、设备及存储介质; 202210760302.3, 一种音床渲染项数据映射方法、装置、设备及存储介质; 202210603204.9, 一种渲染器的渲染项确定方法、装置、设备及存储介质; 202210600880.0, 一种音床输出渲染项确定方法、装置、设备及存储介质; 202210603208.7, 一种对象输出渲染项确定方法、装置、设备及存储介质; 202210603212.3, 一种场景输出渲染项确定方法、装置、设备及存储介质; 202210603184.5, 音频渲染器的渲染项处理方法、装置、设备及存储介质; 202210608202.9, 一种场景渲染项数据映射方法、装置、设备及存储介质; 202210782056.1, 一种音频渲染器增益计算方法、装置、设备及存储介质; 202210910129.0, 用于对象渲染器的元数据解析方法、装置、设备及存储介质; 202210907370.8, 利用元数据对基于对象的音频进行渲染的方法及装置; 202210912275.7, 利用元数据对基于场景的音频进行渲染的方法及装置; 202211057713.2, 利用元数据对基于对象的音频进行渲染的方法及装置; 202211063746.8, 利用元数据对基于场景的音频进行渲染的方法及装置; ZL201510795213.2, 一种 3D 录音系统球面麦克风阵列分布方法; CN112312298A, 音频播放方法及装置、电子设备和存储介质; 202210451743.5, 一种音频处理方法、装置、电子设备和可读存储介质。

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TIAI 125-2023

信息技术 虚拟现实内容表达 音频

1 范围

本文件规定了虚拟现实（Virtual Reality, VR）设备及相关系统中的沉浸式音频内容的表达方式，包括元数据（Metadata）和渲染器（Render）的系统框架及接口规范。

本文件适用于全景音频录播、沉浸式音频通信、虚拟现实音频交互等领域的音频采集、传输、回放系统。

2 规范性引用文件

下列文件中的内容通过文中的规范性引用而构成本文件必不可少的条款。其中，注日期的引用文件，仅该日期对应的版本适用于本文件。不注日期的引用文件，其最新版本（包括所有的修改单）适用于本文件。

GB/T 5271.1-2000 信息技术 词汇 第1部分：基本术语

GB/T 5271.4-2000 信息技术 词汇 第4部分：数据的组织

GB/T 5271.9-2001 信息技术 词汇 第9部分：数据通信

GB/T 17191（所有部分） 信息技术 具有1.5Mbit/s数据传输率的数字存储媒体运动图像及其伴音的编码

GB/T 17975.1 信息技术 运动图像及其伴音信息的通用编码 第1部分：系统

GB/T 33475.3 信息技术 高效多媒体编码 第3部分：音频

GY/T 316 用于节目制作的先进声音系统

ISO 9613-1 声学 户外声传播衰减 第1部分：大气中声吸收的计算（Acoustics Attenuation of sound during propagation outdoors—Part 1: Calculation of the absorption of sound by the atmosphere）

ITU-R BS.1770 测量音频节目响度和真正峰值音频电平的算法（Algorithms to measure audio programme loudness and true-peak audio level）

ITU-R BS.2051 用于节目制作的高级音响系统（Advanced sound system for programme production）

ITU-R BS.2076-2（10/2019） 音频定义模型（Audio definition model）

ITU-R BS.2088 带有元数据的音频节目素材国际交换的长文件格式（Long-form file format for the international exchange of audio programme materials with metadata）

ITU-R BS.2388 音频定义模型和多声道音频文件的使用指南（Usage Guidelines for the Audio Definition Model and Multichannel Audio Files）

3 术语和定义

GB/T 5271.1、GB/T 5271.4、GB/T 5271.9和GB/T 33475.3中的界定以及下列术语和定义适用于本文件。

3.1

3 自由度 3DoF

用户以三维空间的一个点为中心，绕着X、Y和Z轴的任意旋转。在头部运动中，分别对应颈椎的上仰与低垂运动、左右侧倾和左右转动。

3.2

6 自由度 6DoF

用户在3自由度（3.1）的基础上，附加中心点沿X、Y和Z轴三个方向的自由平移。

3.3

沉浸式音频 immersive audio

具有6自由度沉浸感的空间音频效果。

3.4

元数据 metadata

描述音频数据相关信息的数据，包括音频数据的属性和数据间的关系。

3.5

静态元数据 static metadata

与音频内容结构相关的在一定时间段内固定不变的元数据。

3.6

动态元数据 dynamic metadata

与音频内容状态相关的随时间变化的元数据。

3.7

空间音频渲染 spatial audio rendering

采用双耳耳机或扬声器组呈现沉浸式音效的音频信号处理过程。

3.8

耳机渲染 binaural rendering

用双耳耳机呈现沉浸式音效的音频信号处理过程。

3.9

扬声器渲染 loudspeaker rendering

用一组扬声器呈现沉浸式音效的音频信号处理过程。

3.10

混响 reverberation

在声源停止发声后，声音在有边界的空间内持续经过边界面和障碍物的多次反射、散射和吸收，直至消失的声学现象。

3. 11

动态混响 dynamic reverberation

声学场景的切换而产生的动态变化的混响现象。

3. 12

房间脉冲响应 room impulse response

描述房间声学传播时域特性的数据。通过检测从声源发出的脉冲信号在房间中某场点被接收到的数据来表示。

3. 13

采样卷积混响 sampling convolutional reverberation

在真实声学环境的不同场点采集房间脉冲响应，获取真实声学环境混响特性的呈现。也称卷积混响。

3. 14

人工混响 artificial reverberation

用算法或模型产生声学环境的模拟混响效果。

3. 15

头相关传输函数 head related transfer function, HRTF

自由场情况下从点声源到双耳的频域声学传输函数。

3. 16

头相关脉冲响应 head related impulse response, HRIR

自由场情况下从点声源到双耳的脉冲响应，是HRTF在时域的等价表示。

3. 17

场景信号 scene signal

基于一阶/高阶环境声学技术(3.21)所获取的音频信号。

3. 18

声音对象 sound object

被感知为一个整体的声音或由一个声源发出的独立于环境的声音。

3. 19

一阶/高阶环境声学技术 **first order ambisonic/higher order ambisonic, FOA/HOA**

基于Ambisonics原理准确捕获和再现三维音频声场的技术，即通过一阶/高阶球谐函数展开获得音频场景信号的技术。

3.20

空间编码 **spatial coding**

将多个通道的音频信号变换成携带空间信息的FOA/HOA格式的音频信号的处理过程。

4 符号和缩略语

4.1 符号

4.1.1 概述

本文件采用的符号定义同GB/T 33475.3定义。除整型除法外，本文件中使用的数学运算符和优先级与C语言使用的相同。除特别说明外，约定编号和计数从0开始。

4.1.2 算数运算符

下列算术运算符适用于本文件。

$:=$	定义符号。 $a := y$ 表示定义为y的一个名字。		
$+$	加		
$-$	减（二元运算符）或取反（一元前缀运算符）		
$\times$	乘		
a^b	幂，表示a的b次幂，也可表示上标。		
$\wedge$	幂		
$/$	整数除法，结果向0取整。例如，7/4和-7/-4取整为1，-7/4和7/-4取整为-1。		
$\frac{a}{b}$	除法运算，不做取整或四舍五入。		
	绝对值	$ x =x$	当 $x>0$
$ $		$ x =0$	当 $x=0$
		$ x =-x$	当 $x<0$
abs	绝对值		
$\sqrt{x}$	平方根		
sprt	平方根		

$\sum_{i=a}^b f(i)$ 自变量*i*取由*a*到*b*（含*b*）的所有整数值时，函数*f*（*i*）的累加和。

$\log_{10}$ 以10为底的对数

$\ln$ 以*e*为底的对数

$\exp$ 以自然常数*e*为底的指数函数

$\sin$ 正弦函数

$\cos$ 余弦函数

atan2 求*y/x*（弧度表示）的反正切值

hypot 计算直角三角形的斜边长

Alegendre Associated Legendre polynomials 伴随勒让德多项式

size 获取矩阵的行数和列数

4.1.3 逻辑运算符

下列逻辑运算符适合于本文件。

$\parallel$	逻辑或
$\&\&$	逻辑与
$!$	逻辑非

4.1.4 关系运算符

下列关系运算符适用于本文件。

$>$	大于
$>=$	大于或等于
$<$	小于
$<=$	小于或等于
$==$	等于
$\neq$	不等于
$\min[,\dots,]$	参数表中的最小值

4.1.5 位运算符

下列位运算符适用于本文件。

$\&$	与
------	---

4.1.6 赋值

下列赋值运算适用于本文件。

$=$	赋值运算符
$++$	自加， $x++$ 相当于 $x=x+1$ 。当用于数组下标时，在自加运算前先求变量值。

- $+=$ 自加指定值, 例如, $x+=3$ 相当于 $x=x+3$, $x+=(-3)$ 相当于 $x=x+(-3)$ 。
 $-=$ 自减指定值, 例如, $x-=3$ 相当于 $x=x+(-3)$, $x-=(-3)$ 相当于 $x=x-(-3)$ 。

4.1.7 助记符

下列助记符适用于本文件。

- bslbf** 位串, 左位在前, 这里“左”是按GB/T 17191中写的位串的顺序。位串是带单引号的1和0串。如 ‘1000 0001’。位串内的空格是便于阅读的, 无特殊意义。(bitstream left bit first)
uimsbf 无符号整数, 最高有效位优先。(unsigned integer, most significant bit first)

4.2 缩略语

下列缩略语适用于本文件。

- 3DoF** 3自由度 (3 Degree of Freedom)
6DoF 6自由度 (6 Degree of Freedom)
AAMSF AVS音频元数据串行流格式 (Avs Audio Metadata Sequential Format)
ADM 音频定义模型 (Audio Definition Model)
AES 音频工程协会 (Audio Engineering Society)
AGC 自动增益控制 (Automatic Gain Control)
AllRAD 全向空间解码器 (All Round Ambisonic Decoder)
AVS 数字音视频编解码技术标准 (Audio Video coding Standard)
BW64 64位广播波文件 (Broadcast Wave-64bit)
DFT 离散傅里叶变换 (Discrete Fourier Transform)
DRC 动态范围控制 (Dynamic range control)
EQ 均衡器 (Equalization)
FFT 快速傅里叶变换 (Fast Fourier Transform)
FIR 有限长单位脉冲响应 (Finite Impulse Response)
FOA 一阶球谐函数信号 (First Order Ambisonic)
HOA 高阶球谐函数信号 (Higher Order Ambisonic)
HRIR 头相关脉冲响应 (Head Related Impulse Response)
HRTF 头相关传输函数 (Head Related Transfer Function)
IDFT 离散傅里叶逆变换 (Inverse Discrete Fourier Transform)
IR 脉冲响应 (Impulse Response)
ILD 双耳声强差 (Interaural Level Difference)
ITD 双耳时间差 (Interaural Time Difference)
N3D 三维归一化谐波 (Normalized Harmonics of 3-Dimensions)
PCM 脉冲编码调制 (Pulse Code Modulation)
RIR 双耳房间脉冲响应 (Room Impulse Response)
SN3D 三维半归一化谐波 (Semi-Normalized Harmonics of 3-Dimensions)
SNR 信噪比 (Signal to Noise Ratio)
SOFA 面向空间的声学格式 (Spatially Oriented Format for Acoustics)
VBAP 基于矢量的振幅平移 (Vector-Base Altitude Panning)
VR 虚拟现实 (Virtual Reality)
VREXT 虚拟现实扩展元数据 (Virtual Reality Extended Metadata)
XML 可扩展标记语言 (Extensible Markup Language)

5 串行流语法规则

本文件采用的串行流语法规则参考GB/T 33475.3中位流语法规则的定义。串行流描述VR音频元数据及其他辅助信息的串行封装结构。串行流中的每一个数据项用黑体。通过名字、按比特位的长度及其类型和串行传输顺序的助记符来描述。

串行流中被解封装的数据元素所导致的操作依赖于该数据的值及以前解封装的数据元素。下面的语法结构表示数据元素以标准类型出现时的情形。

注1：如无特殊说明，本部分中的“比特位”指二进制位。

注2：本部分语法用“C”代码规定，变量或表达式为非零值时等价于条件为真，变量或表达式为零值时等价于条件为非真。

```
while (condition) {  
    dataElement  
    ...  
}
```

若条件为真，则数据元素组紧接着数据流产生，如此重复直到条件为非真。

```
if (condition) {  
    dataElement  
    ...  
} else {  
    dataElement  
    ...  
}
```

若条件为真，在数据流中产生第一组数据元素，若条件为非真，在数据流中产生第二组数据元素。

```
for (expr1;expr2 ; expr3) {  
    dataElement  
    ...  
}
```

expr1是指定循环初始状态表达式，通常它指定了计数器的初始状态，expr2是指定的每次循环前的测试条件。条件为非真时循环终止，expr3是每次循环结束时执行的表达式，一般是增加计数器。

注3：本结构的最通常用法为

```
for (i=0;i<n;i++) {  
    dataElement  
    ...  
}
```

数据元素组产生n次。数据元素组内的条件结构可能依赖循环控制变量i的值。第一次出现时被置为‘0’，第二次增加到‘1’，如此往复。

switch (expr) {	根据表达式expr的值，产生对应的数据元素。expr的值为
case constcase1:	constcase1时产生数据元素dataElement1，expr的值为
dataElement1	constcase2时产生数据元素dataElement2，以此类推，expr的值为constcasen时产生数据元素dataElementn。当expr的值不等于
break	constcase1, constcase2, ..., constcasen中的任何一个值时，产生
case constcase2:	

```
dataElement2          数据元素dataElementDefault
break
...
case constcase1:
    dataElementn
    break
default:
    dataElementDefault
    break
}
```

本结构的一类变体是在case后不出现break，如

```
switch (expr) {
    case constcase1:
        dataElement1
    case constcase2:
        dataElement2
    case constcase3:
        dataElementn
    case constcase4:
        dataElementn
    default:
        dataElementDefault
}
```

expr的值constcase1时，从对应的case constcase1开始产生数据元素，直到break出现。

expr的值constcase1时产生数据元素dataElement1和dataElement2，expr的值为constcase2时产生数据元素dataElementn

注4：数据元素组中可能含有嵌套结构。为简便起见，当后面只有一个数据元素时“[]”省略。

dataElement[] dataElement是一数组数据，数据元素的个数由上下文而定；

dataElement[n] dataElement[n]是数组数据的第n+1个元素；

dataElement[m][n] dataElement[m][n]是二维数组的第m+1，n+1个元素；

dataElement[l][m][n] dataElement[l][m][n]是三维数组的第l+1，m+1，n+1个元素；

dataElement[m...n] dataElement[m...n]是位m到位n之间包括的位。

6 系统框架

6.1 概述

虚拟现实音频内容表达广义上涉及元数据、渲染器、音频编解码器，本文件采用元数据、渲染器、编解码器在逻辑上相互分离的方式，并主要对元数据和渲染器进行规范。虚拟现实音频适用于不同应用场景，包含全景音频、沉浸音频以及互动音频。

当用于本地存储和制作时，只需要渲染器对元数据进行解析，不涉及元数据编解码及音频编解码过程；当用于传输时（例如直播或双向通信），需要另行在系统层定义元数据+音频流的传输格式。可以根据不同应用场合、不同传输协议的要求定义可行的静态元数据、动态元数据、音频流封装形式。

虚拟现实音频内容表达系统框架见图1。采集端，输入音频信号包括Channel（声道信号，即声床Bed）、Object（声音对象）、Scene（场景信号，基于一阶/高阶环境声学技术FOA/HOA）

或它们的混合形式，VR制作过程根据元数据定义生成基础和扩展元数据信息，本文件定义了AVS音频元数据串行流封装格式AAMSF，见第8章。多声道音频制作系统的关键性指标建议及测试方案可参考附录G，空间音频信号中的声音对象在元数据中用音频对象audioObject字段表示，场景信号采集方式可参考附录D、附录E，常用的场景信号渲染方式可参见附录F。元数据又可以划分为动态元数据和静态元数据，前者是指随着音频流内容实时变化的信息，后者则是在一次传输中固定不变的信息，动态元数据可以伴随音频流传输，具体封装格式根据系统层采用的传输协议类型进行定义，元数据串行流封装后与音频流复接进入传输信道。回放端，渲染器将根据解封装后元数据对解码后的音频文件进行空间音频渲染输出（扬声器、耳机或其他方式）。逻辑上元数据和音频编解码互相独立，且解码器和渲染器之间解耦合。渲染器采取注册制，每个注册的VR渲染器支持同一套元数据的解析。

本文件附录给出了各类独立的VR空间音频渲染技术或渲染模块，适用于不同场景的特定需求，对于支持符合本文件元数据解析的渲染器可作为注册渲染器。

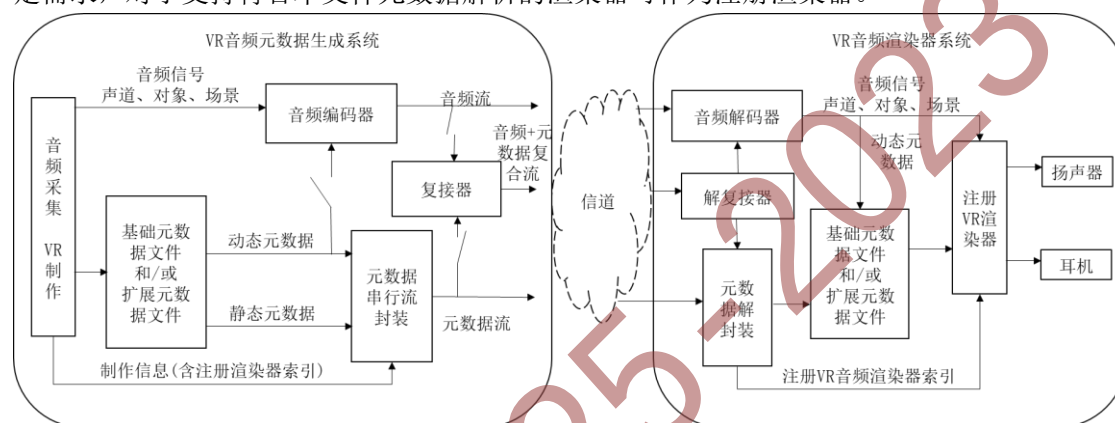


图1 虚拟现实音频内容表达框架示意图

渲染器系统首先进行注册渲染器的选择，之后每个注册渲染器分别进行元数据信息读取和音频文件的读取。渲染器的输入数据由注册渲染器标号以及元数据和音频数据构成，其中元数据和音频数据可以组成BW64（见ITU-R BS.2088）文件格式。渲染器系统中包含多个注册渲染器，以ID号区分，其中注册渲染器ID1的具体定义和描述见第9章（面向双耳耳机输出的基于Ambisonic的渲染器），注册渲染器ID2的具体定义和描述见第10章（面向扬声器输出的基于标准扬声器布局的渲染器）。

注册渲染器模式选择以不同的ID号进行标记，当用于传输时可以预留8个比特对渲染器模式（rendererMode，见8.2节）进行指示，以支持对不同渲染器的灵活选择。

6.2 坐标系语法

坐标系用于描述声源和听者的位置、姿态信息，通过坐标系将位置相关的元数据与渲染器关联起来，实现声源和听者位置动态变化的功能。元数据的位置信息通常使用球极坐标系或者元数据坐标系定义，与ITU-R BS.2076的定义相同。世界坐标系与图形学中的坐标系一致，第9章以世界坐标系作为渲染器ID1的参数格式。音频坐标系在音频计算领域广泛使用，在第9章渲染器ID1中用于球谐函数的计算。

几种坐标系的定义如下：

球极坐标系： θ 为目标点在xy平面上的投影与x轴正向的夹角， φ 为目标点和原点连线与z轴正向的夹角，r为目标点到原点的距离。

元数据坐标系：X指向右边，Y指向屏幕里，Z指向天空，人看向Y轴正向；

世界坐标系：X指向右边，Y指向天空，Z指向屏幕外，人看向Z轴正向；
音频坐标系：X指向屏幕里，Y指向左边，Z指向天空，人看向X轴正向；
坐标系定义如图2：

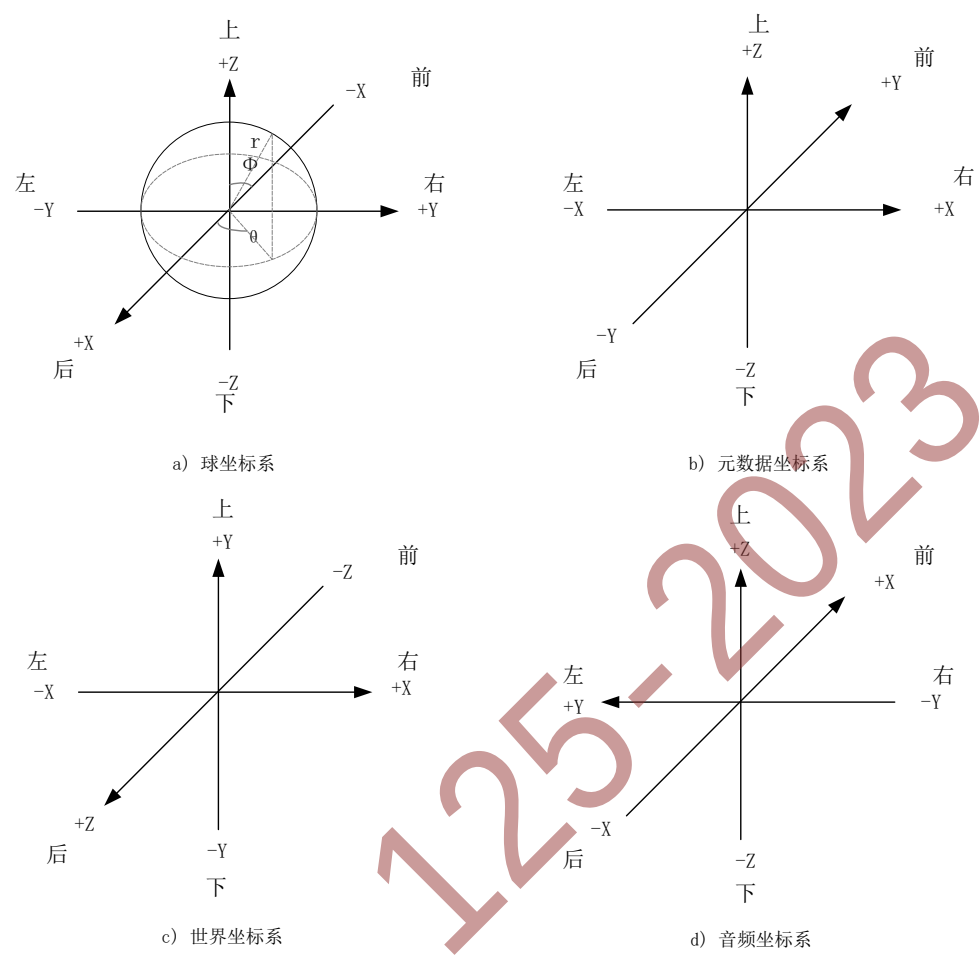


图2 坐标系定义

坐标系之间的转换关系见表1-表4。元数据坐标系转换为世界坐标系语法见表1，世界坐标系转换为传统的音频坐标系语法见表2，球极坐标系转换为传统的音频坐标系语法见表3，世界坐标系转换为球极坐标系语法见表4。

表1 元数据坐标系转换为世界坐标系语法

语法	比特数	助记符
worldPositionFromMetaPosition () {		
$x' = -x;$	8	uimbsf
$y' = z;$	8	uimbsf
$z' = y;$	8	uimbsf
}		

表2 世界坐标系转换为音频坐标系语法

语法	比特数	助记符
audioPositionFromWorldPosition () {		
$x' = z;$	8	uimsbf
$y' = x;$	8	uimsbf
$z' = y;$	8	uimsbf
}		

表3 球极坐标转换为音频坐标系语法

语法	比特数	助记符
audioPositionFromSphericalAngle () {		
$x' = \cos(\text{elevation}) \times \cos(\text{azimuth});$	8×2	uimsbf
$y' = \cos(\text{elevation}) \times \sin(\text{azimuth});$	8×2	uimsbf
$z' = \sin(\text{elevation});$	8	uimsbf
}		

表4 世界坐标系转换为球极坐标语法

语法	比特数	助记符
sphericalFromWorldPosition () {		
$\text{azimuth} = \arctan(x, z);$	8	uimsbf
$\text{elevation} = \arctan(y, \sqrt{x \times x + z \times z});$	8	uimsbf
$\text{distance} = \sqrt{x \times x + y \times y + z \times z};$	8	uimsbf
}		

6.3 元数据模型结构

如图3元数据模型结构。其中，<audioformatExtended>基础部分引用了ITU-R BS.2076定义的ADM，复用了其针对内容和格式的属性和元素，用来传递Bed, Object, HOA, Matrix和Binaural等音频信号相关的内容和控制信息。进一步的，该元数据模型通过<vrExt>扩展部分提供ADM中没有的元数据，以使符合本文件的渲染器在内容生产和渲染环节具有独特的能力。<audioformatExtended>基础部分和<vrExt>扩展部分的元数据有可能会存在属性上的冲突。当出现冲突时，由渲染器决定解决冲突的策略。

基础元数据（basic metadata）是指本文件中采用的包含在ITU-R BS.2076-2（10/2019）第5.10部分规定的AudioFormatExtended中的所有ADM（Audio Definition Model）元素。扩展元数据（extended metadata）是指本文件使用的不属于基础元数据的ADM元素。

元数据的具体定义和解析见第7章。

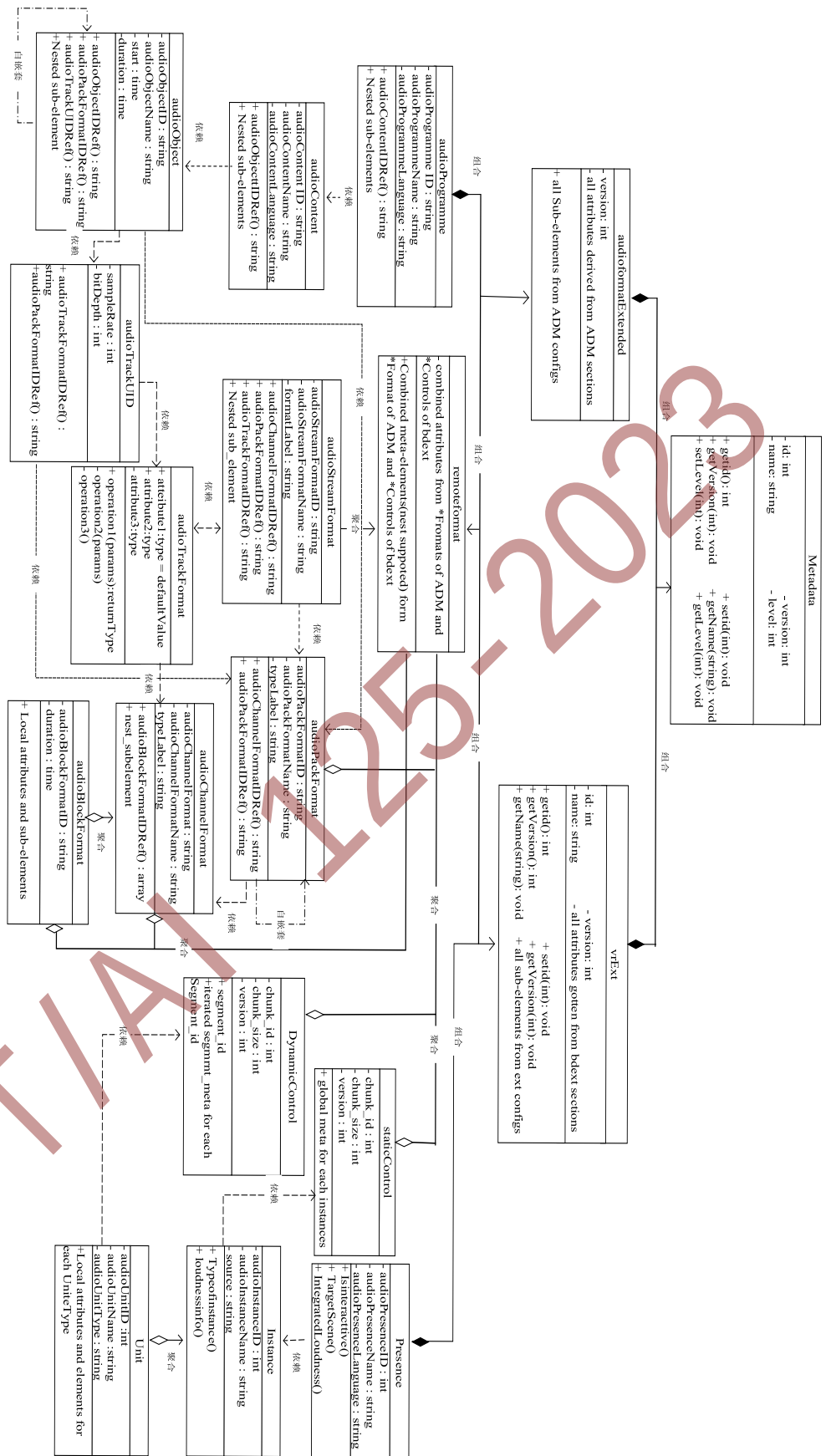


图 3 元数据模型结构

6.4 元数据模型框架语法

元数据块语法见表5。

表5 元数据块语法

语法	比特数	助记符
metadataBlock ()		
{		
basicLevel;	2	uimsbf
numAudioProgrammes;	3	uimsbf
for (int i = 0; i < numAudioProgrammes; ++i) {		
AudioProgramme () ;		
}		
if (hasVrExt == 1) {	1	bslbf
vrExt () ;		
}		
}		

basicLevel是基础元数据的分层，定义参考第7.1节，AudioProgramme () 语法参考第7.3节，vrExt () 语法参考第7.6节。

6.5 渲染器系统框架语法

创建渲染器语法见表6。

表6 创建渲染器语法

语法	比特数	助记符
createAudioRenderer ()		
{		
switch (rendererMode) {	8	uimsbf
case 0x00:		
binauralRenderer () ;		
case 0x80:		
loundspeakerRenderer () ;		
default:		
otherRenderer () ;		
}		
}		

6.6 AAMSF 封装格式

AVS音频元数据串行流封装格式AAMSF及其语法规义见第8章。

6.7 耳机渲染器

面向双耳耳机输出的基于Ambisonics的渲染器（ID1）的系统框架和各部分技术实现的语法和语义见第9章。

6.8 扬声器渲染器

面向扬声器输出的基于标准扬声器布局的渲染器（ID2）的系统框架和各部分技术实现的语法和语义见第10章。

7 元数据定义

7.1 概述

第7章定义渲染相关的元数据，支持符合ITU-R BS.2076的ADM基础元数据，包含<audioformatExtended> 部分和可定制的扩展元数据<vrExt> 部分。描述音频格式的ADM元数据以XML形式给出，可以将其插入BW64文件中。

为了保持设备兼容性，内容的互操作性和渲染系统的复杂度可控，对元数据的数目和组合采用分层（Level）控制，目前定义5级： Level 0 - Level 4， Level 0 是为了保持跟现在的音频内容互操作,主要支持“typeDefinition=DirectSpeakers”且“SpeakerLabel=M+000/M+022/M-022”。 Level 1-4分别对各元素的最大配置见表7， Level 1-3对内容元素数目做限制， Level 4 支持无限的元数据数目。建议的Level配置见表7。

表7 Level 分层建议

<audioformatExtended> Element	描述	Level				
		0	1	2	3	4
audioProgramme	音频文件或音频流中 音频节目数	1	1	4	8	Unlimited
audioContent	文件或者流中节目的 音频内容数目	2（speech/non- speech）	4	8	16	Unlimited
audioObject	文件或者流中音频源 （相当于 vrExt 中的 unit）	2	32	64	128	Unlimited
concurrentAudioObject	一个时间片同时存在 的音频源数	2	8	16	32	Unlimited
interactiveObject	在节目中支持交互的 音频源数目	0	1	2	4	Unlimited
audioObjectNesting	音频源嵌套的层数	0	1	2	4	Unlimited
audioPackFormat	文件（不包含音频 流）中音频格式组的 数目	1	16	32	64	Unlimited
audioChannelFormat	文件（不包含音频 流）中音频格式的数 目	2	32	64	128	Unlimited

表7（续）

<audioformatExtended> Element	描述	Level				
		0	1	2	3	4
audioStreamFormat	文件（不包含音频流）中轨道组格式的数	2	32	64	128	Unlimited
audioTrackFormat	文件（不包含音频流）归音频轨道格式的数目	2	32	64	128	Unlimited
audioTrackUI	音频文件或者音频流中唯一标识符数目	2	32	64	128	Unlimited
surface	同种材料的几何表面	1	8	16	64	Unlimited
vertex	组成 surface 的三角形顶点数，其中三个点组成一个三角形	36	16	16	32	Unlimited

7.2 基础元数据定义

元数据主要使用可扩展标记语言XML编码来实现，XML格式的元数据可包含在BW64格式的音频文件的“axml”或“bxml”块中进行传输。生成的元数据中的“音频包格式标识”、“音频轨道格式标识”和“音轨唯一标识”，将提供给BW64文件的“chna”块，用以将元数据与实际的音轨链接。

元数据基础元素（audioformatExtended）包括：音频节目（audioProgramme，参考BS2076-2第5.8节，见表8）、音频内容（audioContent，参考BS2076-2第5.7节，见表9）、音频对象（audioObject，参考BS2076-2第5.6节，见表10）、音频流格式（audioStreamFormat，参考BS2076-2第5.2节，见表11）、音频轨道格式（audioTrackFormat，参考BS2076-2第5.1节，见表12）、音频包格式（audioPackFormat，参考BS2076-2第5.5节，见表13）、音轨唯一标识（audioTrackUID，参考BS2076-2第5.9节，见表14）、音频通道格式（audioChannelFormat，参考BS2076-2第5.3节，见表15）、音频块格式（audioBlockFormat，参考BS2076-2第5.4节，见表16）。

表8 audioProgramme 相关规范

属性/子元素	规范限制	必选/可选
audioProgrammeID	APR_1001 - APR_1008 dependent on level	必选
audioProgrammeName	32 个字符以内，否则截断	必选
audioProgrammeLanguage	可以为空；如有，必须符合 ISO639-2/T 的规定（3 字符，i.e. "eng" for English）	可选
start	end-start 必选跟 audio file 时长一致，否则以 audio file 为主，格式为 hh:mm:ss.zzzzz，见注 5	必选

表 8（续）

属性/子元素	规范限制	必选/可选
end	与 start 成对使用，格式为 hh:mm:ss.zzzzz，见注 5	必选
maxDuckingDepth	指明节目中对每个 audioObject 允许的最大的自动回避量。范围为 0 - -62 dB	可选
audioContentIDRef	必选跟 audioContent 的 audioContentID 相匹配：最大支持到 16	必选
loudnessMetadata	支持不同"loudnessMethod"的响度信息，根据编解码和渲染器的特性，可能被忽略	可选
audioProgrammeReferenceScreen	只有 screenWidth 可选，其他忽略	可选

注5：时间相关的参数有两种格式，分别为‘hh:mm:ss.zzzzz’或‘hh:mm:ss.zzzzzSffff’，其中‘hh:mm:ss.zzzzz’分别对应小时、分钟、秒。秒的精度至少需要5位，以保证计时精度到一个采样点。‘hh:mm:ss.zzzzzSffff’分别对应小时、分钟、秒，秒使用亚秒的分数表示，zzzzz代表分子，fffff代表分母，精度至少需要5位，这种格式允许使用基于样本的时间表示，其中 zzzzz 是样本数，fffff 是采样率。zzzzz 的值应小于 fffff 以确保小数点小于一。两个值都不应为负，并且 fffff 应大于零。说明：在元数据传输的时候按照第一种格式，第二种格式需要转换为第一种格式后再传输。

表9 audioContent相关规范

属性/子元素	规范限制	必选/可选
audioContentID	ACO_XXXX, hex"XXXX"应该在范围[0X1001, 0X1010]	必选
audioContentName	32 个字符以内，否则截断	必选
audioContentLanguage	可以为空；如有，必须符合 ISO 639-2/T 的规定（3 字符，i.e. "eng" for English）	可选
audioObjectIDRef	必须跟 audioObject 的 audioObjectID 相匹配：最大支持到 128	必选
loudnessMetadata	支持不同"loudnessMethod"的响度信息，根据编解码和渲染器的特性，可能被忽略	可选
dialogue	支持 mixedContentKind，需要取值为 2，否则为 0 或 1	可选
alternativeValueSetIDRef	对 audioObject 中的替代值集的引用。例如 AVS_1001_0001	可选

表10 audioObject相关规范

属性/子元素	规范限制	必选/可选
audioObjectID	AO_XXXX, hex"XXXX"应该在范围[0x1001, 0x1080]	必选
audioObjectName	32 个字符以内，否则截断	必选
start	音频内容的开始时间，格式为 hh:mm:ss.zzzzz，见注 5	必选

表 10（续）

属性/子元素	规范限制	必选/可选
duration	音频内容的时长，格式为 hh:mm:ss.zzzzz，见注 5	必选
dialogue	支持 mixedContentKind，需要取值为 2；否则为 0 或 1	可选
importance	重要性范围: 0-10，渲染器可以设置阈值，低于阈值的音频源丢弃，不参加渲染	可选
interact	是否支持用户跟音频源互动，默认为 0	可选
disableDucking	设为 1，不允许自动回避对象，设为 0，允许回避，默认为 0。	可选
audioPackFormatIDRef	必须跟 audioPackFormat 的 audioPackFormatID 相匹配：最大支持到 8	必选
audioObjectIDRef	嵌套其他 audioObject 的 ID，最大支持 4 层	可选
audioComplementaryObjectIDRef	补充对象 ID 的索引	可选
audioTrackUIDRef	必须跟 audioTrackUID 的 UID 一致，最大支持到 128	必选
audioObjectInteraction	音源是否支持用户互动，取值 0 或 1：0 表示不支持，1 表示支持，默认为 0	可选
gain	所有属于同一个音源的增益	可选
mute	指示音源是否被渲染播放，取值 0 或 1	可选

表11 audioStreamFormat相关规范

属性/子元素	规范限制	必选/可选
audioStreamFormatID	AS_0001xxxx - AS_0005xxxx，分别表示支持 bed 和 matrix，Object，HOA，binaural，其中的 hex"xxxx"跟 audioChannelFormatID 相同	必选
audioStreamFormatName	32 个字符以内，否则截断	必选
formatLabel	音频流类型，按照 ITU-R BS.2388-4 中“自定义音频类型的值为 1001 到 FFFF”，结合 AVS 系统对 streamtype 的规定（依据 GB/T17975.1），定义 AVS2 流为 10D3，AVS3 流为 10D5	必选
formatDefinition	对应 formatLabel 的名字，如 PCM、AVS2、AVS3 等	必选
audioChannelFormatIDRef	必须跟 audioChannelFormat 的 audioChannelFormatID 一致，最大取值 128	可选
audioPackFormatIDRef	必须跟 audioPackFormat 的 audioPackFormatID 一致，最大取值 64	可选
audioTrackFormatIDRef	必须跟 audioTrackFormat 的 auditrackFormatID 一致，最大取值 128	可选

表12 audioTrackFormat相关规范

属性/子元素	规范限制	必选/可选
audioTrackFormatID	AT_0001xxxx_01 - AT_0005xxxx_01, 分别表示支持 bed 和 matrix, Object, HOA, binaural, 其中的 hex"xxxx"跟 audioStreamFormatID 相同	必选
audioTrackFormatName	32 个字符以内, 否则截断	必选
formatLabel	音频流类型, 按照 ITU-R BS.2388-4 中“自定义音频类型的值为 1001 到 FFFF”, 结合 AVS 系统对 streamtype 的规定 (依据 GB/T17975.1), 定义 AVS2 流为 10D3, AVS3 流为 10D5	必选
formatDefinition	对应 formatLabel 的名字, 如 PCM、AVS2、AVS3 等	必选
audioStreamFormatIDRef	必须跟 audioStreamFormat 的 audioStreamFormatID 一致, 最大取值 128	必选

表13 audioPackFormat相关规范

属性/子元素	规范限制	必选/可选
audioPackFormatID	AP_0001xxxx or AP_0003xxxx, 其中 hex"xxxx"取值范围[0x1001, 0x1040] AT_0002xxxx 目前渲染器不支持, 待兼容 AT_0004xxxx 和 AT_0005xxxx 表示 HOA 和 Binaural 支持	必选
audioPackFormatName	32 个字符以内, 否则截断	必选
typeLabel	目前只支持 0001, 0003, 0004, 0005	可选 (但 typeLabel 和 typeDefinition 必须至少一个)
typeDefinition	分别对应 typeLabel: DirectSpeakers, Objects, HOA, Binaural	可选 (但 typeLabel 和 typeDefinition 必须至少一个)
importance	一个音频组的重要性, 0 - 10	可选
audioChannelFormatIDRef	必须跟 audioChannelFormat 的 audioChannelFormatID 一致, 最大取值 128	必选
audioPackFormatIDRef	嵌套, 暂时不支持	可选
absoluteDistance	音频绝对距离 (米)	可选

表14 audioTrackUID相关规范

属性/子元素	规范限制	必选/可选
UID	ATU_00000001 - ATU_00000080 此 UID 值对应音轨的索引号, 使用 16 进制, 最多支持 128 轨。	必选
sampleRate	音轨对应的采样率, 单位 Hz, 例如 48000	可选
bitDepth	音轨对应的位深, 例如 16、24、32	可选

表 14（续）

属性/子元素	规范限制	必选/可选
audioTrackFormatIDRef	audioTrackFormat 的引用 ID，如 AT_00010001_01	可选
audioChannelFormatIDRef	audioChannelFormat 的应用 ID，如 AC_00010001	可选
audioPackFormatIDRef	audioPackFormat 的应用 ID，如 AP_00010002	可选

表15 audioChannelFormat相关规范

属性/子元素	规范限制	必选/可选
audioChannelFormatName	32 个字符以内，否则截断	必选
audioChannelFormatID	AC_0001xxxx or AC_ 0003xxxx，表示支持 bed 和 Object，其中的 hex"xxxx"跟 audioStreamFormatID 相同；AC_0004xxxx 和 AC_0005xxxx 表示 HOA 和 Binaural 支持	必选
typeLabel	目前只支持 0001, 0003, 0004, 0005	必选
typeDefinition	分别对应 typeLabel: DirectSpeakers, Objects, HOA, Binaural	必选
audioBlockFormat	包含 audioChannelFormat 对应流的配置参数信息	必选
frequency	高低通滤波的截止频率	可选

表16 audioBlockFormat相关规范

属性/子元素	规范限制	必选/可选
audioBlockFormatID	AB_0001xxxx_nnnnnnnn or AB_ 0003xxxx_nnnnnnnn, "xxxx"跟 audioChannelFormat 保持一致；nnnnnnnn 是从 00000001 开始计数的 block 序号. 对于 DirectSpeakers 类型，取值应该是固定值: 00000001	必选
rtime	针对 audioObject 的动态元数据开始的相对时间，格式为 hh:mm:ss.zzzzz，见注 5	typeDefinition 为 Objects 才有
duration	audioBlockFormat 时间长度，格式为 hh:mm:ss.zzzzz，见注 5	typeDefinition 为 Objects 才有

audioBlockFormat DirectSpeakers子元数据参考BS.2051-2第三章表9，见表17。

表17 audioBlockFormat DirectSpeakers子元数据（支持到9.1.4）

Channel 名称	SpeakerLabel	位置坐标		
		Azimuth	Elevation	单位
Left (L)	RC_L	30	0	度
Right (R)	RC_R	30	0	度
Center (C)	RC_C	0	0	度
Low-Frequency-Effects (LFE)	RC_LFE	-45	-30	度
Left Side Surround (Lss)	RC_Lss	90	0	度
Right Side Surround (Rss)	RC_Rss	-90	0	度
Left Rear Surround (Lrs)	RC_Lrs	135	0	度
Right Rear Surround (Rrs)	RC_Rrs	-135	0	度
Left Top Front	RC_Lts	45	45	度
Right Top Front	RC_Rts	-45	45	度
Left Top Rear	RC_Lts	135	45	度
Right Top Rear	RC_Rts	135	45	度
Right Surround (Rs)	RC_Rs	110	-15	度

注 6: Azimuth 和 Elevation 的定义符合本文件 6.2 球极坐标定义。

audioBlockFormat Objects子元数据参考BS2076-2第5.4.3.3节，见表18。

表18 audioBlockFormat Objects子元数据

子元素	属性	规范限制	必选/可选
cartesian	是否是元数据坐标, 默认为 0, 表示球极坐标, 为 1 时表示元数据坐标	0 或 1	可选
gain	audioBlockFormat 动态片段的增益	支持线性/对数域, 默认是线性值	可选
importance	audioBlock duration 时间片内的重要性范围: 0 - 10	0-10	可选
position	coordinate="X"	元数据坐标使用 相对位置 [-1,1]	必选
	coordinate="Y"		
	coordinate="Z"	相对位置 [-1, 1]	可选
	coordinate="azimuth"	球极坐标时使用, [-180, 180]	必选
	coordinate="elevation"	球极坐标使用, [-90, 90]	必选
	coordinate="distance"	球极坐标使用, [0, 1]	可选
	coordinate=" screenEdgeLock "	定义了对象音频在屏幕边缘的位置, 如 Left, right, top, bottom	可选

表 18（续）

子元素	属性	规范限制	必选/可选
width		相对位置 [0, 1]	可选
depth			
height			
diffuse		散射系数[0.0, 1.0]	可选
channelLock	maxDistance	设定对象锁定到固定扬声器的最大球面距离	可选
jumpPosition	interpolationLength	如果 jumpPosition 设置为 1，位置从前一个 block 的位置跳变为当前位置，如果是 0，将在整个 block 的长度上进行插值。如果使用了‘interpolationLength’，而且 jumpPosition 的值为 1，则使用 interpolation 的长度做插值，其长度不应超过整个 block 的长度	可选
zoneExclusion		指示哪些扬声器/房间区域不渲染，指定的区域限制见表 18	可选
objectDivergence	azimuthRange	调整对象的指定位置与 azimuthRange 值指定的其他两个位置之间的平衡，objectDivergence 的值为 0 表示没有分歧。 该属性仅在坐标系为球面时使用，objectDivergence 的取值为 0- 1.0，azimuthRange 取值为 0-180 度。	可选
	positionRange	调整对象的指定位置与由 positionRange 值指定的其他两个位置之间的平衡，objectDivergence 的值为 0 表示没有分歧。 该属性仅在坐标系为元数据坐标系时使用。objectDivergence 的取值为 0- 1.0，positionRange 的取值为 0.0 to 1.0	
screenRef		指组件是否与屏幕相关 ‘0’：不相关； ‘1’：相关；默认值为‘0’	可选
注 7：positionRange 或 azimuthRange 属性不得同时出现在 objectDivergence 元素中。			

Zone排除空间区域定义见表19。

表19 Zone排除空间区域定义

ZoneExclusionLabel	区域描述	坐标参数					
		minX	maxX	minY	maxY	minZ	maxZ
ZEL1	Back Zone	-1.00	1.00	-1.00	-0.42	-0.50	0.50
ZEL2L	Side Zone	-1.00	-0.76	-0.42	0.84	-0.50	0.50
ZEL2R		0.76	1.00	-0.42	0.84	-0.50	0.50
ZEL3L	Center-back Zone	-1.00	-0.16	0.50	1.00	-0.50	0.50
ZEL3Lss		-1.00	-0.52	-0.71	0.50	-0.50	0.50
ZEL3R		0.16	1.00	0.50	1.00	-0.50	0.50
ZEL3Rss		0.52	1.00	-0.71	0.50	-0.50	0.50
ZEL4	Screen Zone	-1.00	1.00	-1.0	0.84	-0.50	0.50
ZEL5	Surround Zone	-1.00	1.00	0.50	1.00	-0.50	0.50
ZELT	Top Elevation Zone	-1.00	1.00	-1.00	1.00	0.50	1.00
ZELB	Bottom Elevation Zone	-1.00	1.00	-1.00	1.00	-1.00	-0.50

注 8: ZoneExclusion 可以用元数据坐标或者球极坐标表示, 此处以元数据坐标规范排除空间的区域, 球极坐标表示方法可以从上表的元数据坐标转换而来。见 BS2076-2 第 5.4.3.4 节。

audioBlockFormat HOA子元数据参考BS2076-2第5.4.3.4节, 见表20。

表20 audioBlockFormat HOA子元数据

子元素	属性	规范限制	必选/可选
equation	描述 HOA 系数的获取公式, 仅是描述作用	暂无	可选
order	HOA 的阶数	最高支持到 7 阶	必选
degree	HOA 角度		必选
normalization	HOA 系数的归一化方式	支持 N3D, SN3D 和 FuMa (参考 ITU-R BS.2076-2 第 11.2 节), 默认是 SN3D	可选
nfcRefDist	近场补偿的相对距离 (米)		可选
screenRef	HOA 音频是否视频屏幕位置相关	0/1 0: 屏幕位置不相关 1: 屏幕位置相关	可选

7.3 基础元数据语法

音频节目语法见表21。

表21 音频节目语法

语法	比特数	助记符
AudioProgramme () {		
audioProgrammeID;	8 × 8	uimsbf
audioProgrammeName;	32 × 8	uimsbf
programmeStart;	27	uimsbf
programmesDuration;	27	uimsbf
hasAudioProgrammeLanguage;	1	bslbf
hasMaxDuckingDepth;	1	bslbf
hasLoudnessMetadata;	1	bslbf
hasAudioProgrammeReferenceScreen;	1	bslbf
if (hasAudioProgrammeLanguage) {		
audioProgrammeLanguage;	4	uimsbf
}		
if (hasMaxDuckingDepth) {		
maxDuckingDepth;	10	uimsbf
}		
if (hasLoudnessMetadata) {		
LoudnessMetadata () ;		
}		
if (hasAudioProgrammeReferenceScreen) {		
AudioProgrammeReferenceScreen () ;		
}		
numContents;	4	uimsbf
for (i = 0; i < numContents; i++) {		
audioContentRefID;	8 × 8	uimsbf
}		
}		

音频内容语法见表22。

表22 音频内容语法

语法	比特数	助记符
AudioContent () {		
audioContentID;	8 × 8	uimsbf
audioContentName;	32 × 8	uimsbf
hasAudioContentLanguage;	1	bslbf
hasLoudnessMetadata;	1	bslbf

表 22 (续)

语法	比特数	助记符
hasDialogue;	1	bslbf
if (hasAudioContentLanguage) {		
audioContentLanguage;	4	uimsbf
}		
if (hasLoudnessMetadata) {		
LoudnessMetadata ();		
}		
if (hasDialogue) {		
Dialogue ();		
}		
numObjects;	7	uimsbf
for (i = 0; i < numObjects; i++) {		
audioObjectRefID;	11 × 8	uimsbf
}		
}		

对话语法见表23。

表23 对话语法

语法	比特数	助记符
Dialogue () {		
dialogueAttribute	2	uimsbf
dialogueType	3	uimsbf
}		

音频对象语法见表24。

表24 音频对象语法

语法	比特数	助记符
AudioObject () {		
audioObjectID;	11 × 8	uimsbf
audioObjectName;	32 × 8	uimsbf
objectStart;	27	uimsbf
objectDuration;	27	uimsbf
hasAudioObjectLanguage;	1	bslbf
hasDialogue;	1	bslbf
hasAudioObjectImportance;	1	bslbf
hasDisableDucking;	1	bslbf
hasInteract;	1	bslbf
hasGain;	1	bslbf

表 24 (续)

语法	比特数	助记符
hasHeadLocked;	1	bslbf
hasMute;	1	bslbf
if (hasAudioObjectLanguage) {		
audioObjectLanguage;	4	uimsbf
}		
if (hasDialogue) {		
Dialogue () ;		
}		
if (hasAudioObjectImportance) {		
audioObjectImportance;	4	uimsbf
}		
if (hasInteract) {		
interact;	1	uimsbf
}		
if (hasGain) {		
objectGainUnit;	1	uimsbf
objectGain;	8	uimsbf
}		
numComplementaryObjectRefID;	2	uimsbf
for (i = 0; i < numComplementaryObjectRefID; i++) {		
audioComplementaryObjectRefID;	11×8	uimsbf
}		
numPacks;	7	uimsbf
for (i = 0; i < numPacks; i++) {		
audioPackFormatRefID;	11 × 8	uimsbf
}		
numTacks;	7	uimsbf
for (i = 0; i < numTacks; i++) {		
audioTrackUIDRefID;	12 × 8	uimsbf
}		
}		

音频包格式语法见表25。

表25 音频包格式语法

语法	比特数	助记符
AudioPackFormat () {		
audioPackFormatID;	11 × 8	uimsbf
audioPackFormatName;	32 × 8	uimsbf

表 25（续）

语法	比特数	助记符
typeLabel;	3	uimsbf
hasAudioPackFormatImportance;	1	bslbf
if （hasAudioPackFormatImportance ） {		
audioPackFormatImportance;	4	uimsbf
}		
absoluteDistance;	14	uimsbf
numChannels;	7	uimsbf
for （i = 0; i < numchannels; i++） {		
audioChannelFormatRefID;	11 × 8	uimsbf
}		
}		

音频通道格式语法见表26。

表26 音频通道格式语法

语法	比特数	助记符
AudioChannelFormat （） {		
audioChanneFormatID;	11 × 8	uimsbf
audioChannelFormatName;	32 × 8	uimsbf
typeLabel;	3	uimsbf
numBlocks;	16	uimsbf
for （i = 0; i < numBlocks; i++） {		
AudioBlockFormat （） ;		
}		
}		

音频轨道UID语法见表27。

表27 音频轨道UID语法

语法	比特数	助记符
AudioTrackUID （） {		
UID;	12 × 8	uimsbf
bitDepth;	2	uimsbf
sampleRate;	4	uimsbf
audiochannelFormatRefID;	11 × 8	bslbf
}		

音频块格式语法见表28。

表28 音频块格式语法

语法	比特数	助记符
AudioBlockFormat () {		
audioBlockFormatID	20 × 8	uimsbf
rstart;	27	uimsbf
duration;	27	uimsbf
gain;	8	uimsbf
if (typeLabel == 0001) {		
speakerLable;	4	uimsbf
}		
else if (typelabel == 0003) {		
if (cartisian) {	1	bslbf
azimuth;	15	uimsbf
elevation;	14	uimsbf
distance;	7	uimsbf
} else {		
x;	7	uimsbf
y;	7	uimsbf
z;	7	uimsbf
}		
if (hasSize) {	1	bslbf
width;	8	uimsbf
height;	8	uimsbf
depth;	8	uimsbf
}		
if (hasImportance) {	1	bslbf
importance;	4	uimsbf
}		
if (hasDiffuse) {	1	bslbf
diffuse;	6	uimsbf
}		
if (hasChannelLock) {	1	bslbf
channelLock;	6	uimsbf
}		
if (hasJumpPosition) {	1	bslbf
jumpPosition;	2	uimsbf
interpolationLength;	12	uimsbf
}		
if (hasObjectDivergence) {	1	bslbf
objectDivergence;	4	uimsbf
azimuthRange;	8	uimsbf

表 28（续）

语法	比特数	助记符
positionRange;	4	uimsbf
}		
if (hasScreenEdgeLock) {	1	bslbf
screenEdgeLock;	2	uimsbf
}		
} else if (type == 0004) {		
order;	3	uimsbf
degree;	4	uimsbf
normalization;	2	uimsbf
if (hasNfcRefDist) {	1	bslbf
nfcRefDist;	6	uimsbf
}		
if (hasScreenRef) {	1	bslbf
screenRef;	1	uimsbf
}		
}		
}		

响度元数据语法见表29。

表29 响度元数据语法

语法	比特数	助记符
LoudnessMetadata () {		
integratedLoudness;	5	uimsbf
loudnessRange;	5	uimsbf
maxTruePeak;	5	uimsbf
maxMomentary;	5	uimsbf
maxShortTerm;	5	uimsbf
dialogueLoudness;	5	uimsbf
}		

音频节目参考屏幕的语法见表30。

表30 音频节目参考屏幕语法

语法	比特数	助记符
AudioProgrammeReferenceScreen () {		
cartesianReferenceScreen;	1	uimsbf
aspectRatio;	3	uimsbf
if (cartesianReferenceScreen == 0) {		
screenCentrePositionAzimuth	15	uimsbf

表 30 (续)

语法	比特数	助记符
screenCentrePositionElevation	14	uimsbf
screenCentrePositionDistance	7	uimsbf
screenWidth_polar	7	uimsbf
} else {		
screenCentrePositionX	7	uimsbf
screenCentrePositionY	7	uimsbf
screenCentrePositionZ	7	uimsbf
screenWidth_cartesian	7	uimsbf
}		
}		

音频对象交互语法见表31。

表31 音频对象交互语法

语法	比特数	助记符
AudioObjectInteraction () {		
onOffInteract;	1	uimsbf
gainInteract;	1	uimsbf
positionInteract;	1	uimsbf
if (gainInteract) {		
gainInteractionUnit;	1	uimsbf
gainInteractionRangeMin;	7	uimsbf
gainInteractionRangeMax;	7	uimsbf
}		
if (positionInteract) {		
cartesianInteraction	1	uimsbf
if (cartesianInteraction == 1) {		
positionInteractionRangeXmin;	7	uimsbf
positionInteractionRangeXmax;	7	uimsbf
positionInteractionRangeYmin;	7	uimsbf
positionInteractionRangeYmax;	7	uimsbf
positionInteractionRangeZmin;	7	uimsbf
positionInteractionRangeZmax;	7	uimsbf
} else {		
positionInteractionRangeAzimuthMin;	15	uimsbf
positionInteractionRangeAzimuthMax;	15	uimsbf
positionInteractionRangeElevationMin;	14	uimsbf
positionInteractionRangeElevationMax;	14	uimsbf
positionInteractionRangeDistanceMin;	7	uimsbf

表 31（续）

positionInteractionRangeDistanceMax;	7	uimsbf
}		
}		
}		

区域排除语法见表32。

表32 区域排除语法

语法	比特数	助记符
ZoneExclusion () {		
minX;	7	uimsbf
maxX;	7	uimsbf
minY;	7	uimsbf
maxY;	7	uimsbf
minZ;	7	uimsbf
maxZ;	7	uimsbf
}		

7.4 基础元数据语义

基础元数据的语义见表33。

表33 基础元数据的语义

名称	语义
AudioProgramme()	音频节目，是由一个或多个 audioContent 组成的集合。包含节目的开始时间和结束时间，可用于对齐视频时间码。还包括响度元数据，以便记录节目的响度
audioProgrammeID	8 字符，音频节目 ID，例如“APR_0001”，用于唯一标识音频节目
audioProgrammeName	32 字符，音频节目名字，例如“concert music”，建议包含音频节目的特点
programmeStart	27 比特，节目开始时间，如 10 时：11 分：12 秒：300 毫秒，其中 5 比特表示小时，6 比特表示分钟，6 比特表示秒数，10 比特表示毫秒
programmesDuration	27 比特，节目持续时长，如 10 时：11 分：12 秒：300 毫秒，其中 5 比特表示小时，6 比特表示分钟，6 比特表示秒数，10 比特表示毫秒
hasAudioProgrammeLanguage	1 比特，表示 AudioProgramme 是否含有 audioProgrammeLanguage，‘0’：没有，‘1’：有
hasMaxDuckingDepth	1 比特，表示 AudioProgramme 是否含有 maxDuckingDepth，‘0’：没有，‘1’：有
hasLoudnessMetadata	1 比特，表示 AudioProgramme 是否含有 maxDuckingDepth，‘0’：没有，‘1’：有
hasAudioProgrammeReferenceScreen	1 比特，表示 audioProgrammeReferenceScreen 是否含有 maxDuckingDepth，‘0’：没有，‘1’：有

表 33 (续)

名称	语义
audioProgrammeLanguage	4 比特, 表示 AudioProgramme 里对话的语言, '0': 汉语, '1': 英语, '2': 法语, '3': 西班牙语, '4': 葡萄牙语, '5': 德语, '6'-'15': 保留
maxDuckingDepth	10 比特, 指明节目中对每个 AudioObject () 允许的最大的自动回避量, 取值为 0~62dB, 步长为 0.0605, 最高位为符号位, "1"表示负数, "0"表示正数
LoudnessMetadata ()	响度校正接口, 参考 ITU-R BS.1770 响度算法对音频进行修正
AudioProgrammeReferenceScreen ()	屏幕尺寸解码接口, 规范有关 AudioProgramme () 的参考/制作/监控屏幕尺寸
numContents	4 比特, 表示 AudioProgramme 里引用的 audioContentRefID 的个数
audioContentRefID	8 字符, 表示 AudioProgramme 包含的 audioContent 的索引
AudioContent ()	音频内容, 由一个或多个 audioObject 组成, 给出了对音频内容的描述, 有如语言和响度参数
audioContentID	8 字符, 表示 AudioContent 的唯一索引值, 例如 ACO_0001
audioContentName	32 字符, 音频内容名字, 例如"background_music", 建议包含音频内容的特点
hasAudioContentLanguage	1 比特, 表示 AudioContent 里是否存在 audioContentLanguage 字段, '0': 不存在, '1': 存在
hasLoudnessMetadata	1 比特, 表示 AudioContent 里是否存在 LoudnessMetadata (), '0': 不存在, '1': 存在
hasDialogue	1 比特, 表示 AudioContent 里是否存在 dialogue 字段, '0': 不存在, '1': 存在
audioContentLanguage	4 比特, 表示 AudioContent 里对话的语言, '0': 汉语, '1': 英语, '2': 法语, '3': 西班牙语, '4': 葡萄牙语, '5': 德语, '6'-'15': 保留
LoudnessMetadata ()	响度校正接口, 参考 ITU-R BS.1770 响度算法对音频进行修正
Dialogue ()	对话内容接口, 表示对内容类型的详细描述
numObjects	7 比特, 表示 AudioContent 里引用的 audioObjectRefID 的个数
audioObjectRefID	11 字符, 表示 AudioContent 包含的 audioObject 的索引
dialogueAttribute	2 比特, 表示对话内容类型, 取值见表 9, 更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 33
名称	语义
dialogueType	3 比特, 表示 dialogueAttribute 包含的内容种类, 取值见表 9, 更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 34
AudioObject ()	音频对象, 用来关联音频内容与格式
audioObjectID	11 字符, 表示 AudioObject 的唯一索引值
audioObjectName	32 字符, 音频内容名字, 例如"guitar_music", 建议包含音频对象的特点
objectStart	27 比特, 音频对象相对于音频节目的开始时间, 如 00 时: 11 分: 12 秒: 300 毫秒, 其中 5 比特表示小时, 6 比特表示分钟, 6 比特表示秒数, 10 比特表示毫秒
objectDuration	27 比特, 音频对象相对于音频节目的开始时间, 如 00 时: 11 分: 12 秒: 300 毫秒, 其中 5 比特表示小时, 6 比特表示分钟, 6 比特表示秒数, 10 比特表示毫秒
hasAudioObjectLanguage	1 比特, 表示 AudioObject 里是否存在 AudioObjectLanguage 字段, '0': 不存在, '1': 存在
hasDialogue	1 比特, 表示 AudioObject 里是否存在 dialogue 字段, '0': 不存在, '1': 存在

表 33 (续)

名称	语义
hasAudioObjectImportance	1 比特, 表示 AudioObject 里是否存在 audioObjectImportance 字段, '0': 不存在, '1': 存在
hasDisableDucking	1 比特, 表示 AudioObject 里是否存在 disableDucking 字段, '0': 不存在, '1': 存在
hasInteract	1 比特, 表示 AudioObject 里是否存在互动字段, '0': 不存在, '1': 存在
hasGain	1 比特, 表示 AudioObject 里是否存在 gain 字段, '0': 不存在, '1': 存在
hasHeadLocked	1 比特, 表示 AudioObject 里是否存在 headLocked 字段, '0': 不存在, '1': 存在
hasMute	1 比特, 表示 AudioObject 里是否存在 mute 字段, '0': 不存在, '1': 存在
audioObjectLanguage	4 比特, 表示 AudioObject 里对话的语言, '0': 汉语, '1': 英语, '2': 法语, '3': 西班牙语, '4': 葡萄牙语, '5': 德语, '6'-'15': 保留
Dialogue ()	对话内容接口, 表示对内容类型的详细描述
audioObjectImportance	4 比特, 表示 AudioObject 的重要性, '10': 重要性最高, '0': 重要性最低, '11'-'15': 保留
objectGainUnit	1 比特, 表示 objectGain 的单位。'0': 线性, '1': dB
objectGain	8 比特, 表示应用于 AudioObject () 参考的所有音频样本的增益值, 取 0.0-16.0, 步长为 0.0625
audioComplementaryObjectRefID	11 字符, 指定与当前 audioObject 互斥的 audioObject 的索引值
numPacks	7 比特, 表示 AudioObject 里引用 audioPackFormatRefID 的个数
audioPackFormatRefID	11 字符, 表示 AudioObject 包含的 audioPackFormat 的索引
numTracks	7 比特, 表示 AudioObject 里引用 audioTrackUIDRefID 的个数
audioTrackUIDRefID	12 字符, 表示 AudioObject 包含的 audioTrackUIDRefID 的索引
AudioPackFormat ()	音频包, 将一个或多个属于彼此的 AudioChannelFormat 组织在一起
audioPackFormatID	11 字符, 表示 AudioPackFormat 的唯一索引值
audioPackFormatName	32 字符, 音频包名字
typeLabel	3 比特, 表示有关音频包类型的描述, 值的定义见表 13, 更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 10
hasAudioPackFormatImportance	1 比特, 表示 AudioPackFormat 里是否存在 audioPackFormatImportance 字段, '0': 不存在, '1': 存在
audioPackFormatImportance	4 比特, 表示 audioObject 的重要性。'10': 重要性最高, '0': 重要性最低, '11'-'15': 保留
absoluteDistance	14 比特, 表示绝对距离, 取 0.00-100.00, 其中 7 比特表述米数, 7 比特表示厘米数
numChannels	7 比特, 表示 AudioPackFormat 里引用 audioChannelFormatRefID 的个数
audioChannelFormatRefID	11 字符, 表示 AudioPackFormat 里引用 audioChannelFormatRefID 的索引
AudioChannelFormat ()	对单个音频波形的一种描述

表 33 (续)

名称	语义
audioChannelFormatID	11 字符, 表示 AudioChannelFormat 的唯一索引值
audioChannelFormatName	32 字符, 音频通道名字
typeLabel	3 比特, 表示有关声道类型的描述, 值的定义见表 15, 更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 10
channelGainUnit	1 比特, 表示 channelGain 的单位。‘0’: 线性, ‘1’: dB
numBlocks	16 比特, 表示 AudioChannelFormat 里引用 audioBlockFormat 的个数
AudioTrackUID ()	音频轨道, 描述单个音频轨道的索引、采样率、位深等参数
UID	12 字符, 表示 AudioTrackUID 的唯一索引值
bitDepth	2 比特, 表示 AudioTrackUID 的对应音频位深, ‘0’:8 比特, ‘1’:16 比特, ‘2’:24bit, ‘3’:32 比特
sampleRate	4 比特, 表示 AudioTrackUID 的对应音频采样率, ‘0’:8000, ‘1’:16000, ‘2’:24000, ‘3’:32000, ‘4’:44100, ‘5’:48000, ‘6’:96000, ‘7-16’: 保留
AudioBlockFormat ()	音轨或音频帧的详细参数, 包含随时间变化的参数
audioBlockFormatID	20 字符, 表示 AudioBlockFormat 的唯一索引值
rstart	27 比特, 音频块相对于音频对象的开始时间, 如 00 时: 00 分: 12 秒: 300 毫秒, 其中 5 比特表示小时, 6 比特表示分钟, 6 比特表示秒数, 10 比特表示毫秒
duration	27 比特, 音频块相对于 rstart 的持续时间, 如 00 时: 00 分: 12 秒: 300 毫秒, 其中 5 比特表示小时, 6 比特表示分钟, 6 比特表示秒数, 10 比特表示毫秒
gain	8 比特, 表示每个 block 对应的 channel 的增益, 取 0-16, 步长为 0.0625
speakerLable	4 比特, 当 typeLabel 的值为 0001 时使用, 取值参考表 12
cartesian	1 比特, 表示坐标是否为元数据坐标, ‘0’: 球极坐标, ‘1’: 元数据坐标, 默认为 0
azimuth	15 比特, 当 cartesian 为 0 时, 声源的水平角, 取-180~+180, 其中 b14 表示符号位, “1”表示负数, “0”表示正数, b13-b6 表示度数, b5-b0 比特表示角分
elevation	14 比特, 当 cartesian 为 0 时, 声源的俯仰角, 取-90~+90, 其中 b13 表示符号位, “1”表示负数, “0”表示正数, b12-b6 表示度数, b5-b0 比特表示角分
distance	7 比特, 当 cartesian 为 0 时, 声源的归一化距离, 取 0-1, 步长为 0.0078125
x	7 比特, 当 cartesian 为 1 时, 声源的归一化 x 坐标, 取-1~1, 步长为 0.015625, 其中 b6 为符号位, “1”表示负数, “0”表示正数
y	7 比特, 当 cartesian 为 1 时, 声源的归一化 y 坐标, 取-1~1, 步长为 0.015625, 其中 b6 为符号位, “1”表示负数, “0”表示正数
z	7 比特, 当 cartesian 为 1 时, 声源的归一化 z 坐标, 取-1~1, 步长为 0.015625, 其中 b6 为符号位, “1”表示负数, “0”表示正数
hasScreenEdgeLock	1 比特, 表示是否存在屏幕边缘锁, ‘1’: 存在, ‘0’: 不存在。
screenEdgeLock	2 比特, 表示屏幕边缘锁的取值, ‘0’:Left, ‘1’: right, ‘2’: top, ‘3’: bottom
width	8 比特, 对象音频的声源宽度, 取 0.00-2.00, 表示 0-200 厘米
height	8 比特, 对象音频的声源高度, 取 0.00-2.00, 表示 0-200 厘米

表 33（续）

名称	语义
depth	8 比特, 对象音频的声源深度, 取 0.00-2.00, 表示 0-200 厘米
hasImportance	1 比特, 表示 AudioBlockFormat 时候存在 importance 属性, '0': 不存在, '1': 存在
importance	4 比特, 表示 AudioBlockFormat 的重要性, '10': 重要性最高, '0': 重要性最低, '11'-'15': 保留
hasDiffuse	1 比特, 表示 AudioBlockFormat 时候存在 diffuse 属性, '0': 不存在, '1': 存在
diffuse	4 比特, 表示对象音频的散射率, 取值范围[0.0, 1.0], 步长 0.1
hasChannelLock	1 比特, 表示 AudioBlockFormat 时候存在 channelLock 属性, '0': 不存在, '1': 存在
channelLock	6 比特, 设定 object snap 到固定 speaker 的最大球面距离
hasJumpPosition	1 比特, 示 AudioBlockFormat 时候存在 jumpPosition 属性, '0': 不存在, '1': 存在
jumpPosition	2 比特, 对象音频的插值模式, '0': 不插值, '1':按照 interpolationLength 指定位置插值, '2': 在 block 完整区域插值
interpolationLength	12 比特, 动态数据差值的长度, 最大能表示 4096 个采样点
hasObjectDivergence	1 比特, 表示是否存在对象发散, '1': 存在, '0': 不存在。
objectDivergence	4 比特, 表示对象发散值, 取值为 0.0-1.0, 步长为 0.1。
azimuthRange	8 比特, 调整对象的指定位置与 azimuthRange 值指定的其他两个位置之间的平衡, objectDivergence 的值为 0 表示没有分歧。该属性仅在坐标系为球面时使用, azimuthRange 取值为 0-180 度。
positionRange	4 比特, 调整对象的指定位置与由 positionRange 值指定的其他两个位置之间的平衡, 该属性仅在坐标系为元数据坐标系时使用。positionRange 的取值为 0.0 to 1.0, 步长为 0.1
order	3 比特, Ambisonic 通道音频的阶数, 取 1-7
degree	4 比特, Ambisonic 通道音频的度数, 取-order~+order
normalization	2 比特, Ambisonic 通道音频的归一化方式, '0': SN3D, '1': N3D, '2': FuMa, 默认为 0
hasNfcRefDist	1 比特, 表示 AudioBlockFormat 时候存在 nfcRefDist 属性, '0': 不存在, '1': 存在
nfcRefDist	6 比特, HOA 近场补偿距离
hasScreenRef	1 比特, 表示 AudioBlockFormat 时候存在 screenRef 属性, '0': 不存在, '1': 存在
screenRef	1 比特, HOA 音频是否视频屏幕位置相关, '0': 不相关, '1': 相关
LoudnessMetadata ()	响度解码接口, 参考 ITU-R BS.1770 响度算法对音频进行修正
integratedLoudness	5 比特, 表示聚合响度值, -32~0dB, 其中 b4 为符号位, "1"表示负数, "0"表示正数
loudnessRange	5 比特, 表示响度范围, -32~0dB 其中 b4 为符号位, "1"表示负数, "0"表示正数
maxTruePeak	5 比特, 表示最大真正峰值, -32~0dB 其中 b4 为符号位, "1"表示负数, "0"表示正数
maxMomentary	5 比特, 表示最大瞬时响度, -32~0dB 其中 b4 为符号位, "1"表示负数, "0"表示正数

表 33（续）

名称	语义
maxShortTerm	5 比特，表示最大短期响度，-32~0dB 其中 b4 为符号位，“1”表示负数，“0”表示正数
dialogueLoudness	5 比特，表示平均对话的响度，-32~0dB 其中 b4 为符号位，“1”表示负数，“0”表示正数
AudioProgrammeReferenceScreen（）	屏幕尺寸解码接口，规范有关 AudioProgramme（）的参考/制作/监控屏幕尺寸
cartesianReferenceScreen	1 比特，表示是否是元数据坐标系
aspectRatio	3 比特，表示屏幕的宽高比的映射表，‘0’：16:9，‘1’：21:9，‘2’-‘7’：保留
screenCentrePositionAzimuth	15 比特，表示屏幕中心的方位角，取-180~+180，其中 b14 为符号位，“1”表示负数，“0”表示正数，b13-b6 表示度数，b5-b0 比特表示角分
screenCentrePositionElevation	14 比特，表示屏幕中心的高度，取-90~+90，其中 b13 为符号位，“1”表示负数，“0”表示正数，b12-b6 表示度数，b5-b0 比特表示角分
screenCentrePositionDistance	7 比特，表示至屏幕中心的归一化距离，取 0~1，步长为 0.0078125
screenWidth_polar	7 比特，表示球极坐标形式的屏幕宽度，取 0~1，步长为 0.0078125
screenCentrePositionX	7 比特，表示屏幕中心的归一化 X 坐标，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
screenCentrePositionY	7 比特，表示屏幕中心的归一化 Y 坐标，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
screenCentrePositionZ	7 比特，表示屏幕中心的归一化 Z 坐标，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
screenWidth_cartesian	7 比特，表示元数据坐标系形式归一化的屏幕宽度，取 0~1，步长为 0.015625，其中最高位为符号位
AudioObjectInteraction（）	对象交互接口，规范参考表 31
onOffInteract	1 比特，若用户能开或关对象，则设为 1，否则设为 0
gainInteract	1 比特，若用户能改变对象的增益，则设为 1，否则设为 0
positionInteract	1 比特，若用户能改变对象的位置，则设为 1，否则设为 0
gainInteractionUnit	1 比特，表示 gainInteractionRange 的单位。‘0’：线性‘1’：dB
gainInteractionRangeMin	7 比特，表示可能的用户增益互动的最小线性增益因子或对数增益偏差
gainInteractionRangeMax	7 比特，表示可能的用户增益互动的最大线性增益因子或对数增益偏差
cartesianInteraction	1 比特，表示是否是元数据坐标系
positionInteractionRangeXmin	7 比特，表示可能的用户位置交互的最小 X 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
positionInteractionRangeXmax	7 比特，表示可能的用户位置交互的最大 X 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数

表 33（续）

名称	语义
positionInteractionRangeYmin	7 比特，表示可能的用户位置交互的最小 Y 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
positionInteractionRangeYmax	7 比特，表示可能的用户位置交互的最大 Y 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
positionInteractionRangeZmin	7 比特，表示可能的用户位置交互的最小 Z 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
positionInteractionRangeZmax	7 比特，表示可能的用户位置交互的最大 Z 轴归一化偏移值，取-1~1，步长为 0.015625，其中最高位为符号位，“1”表示负数，“0”表示正数
positionInteractionRangeAzimuthMin	15 比特，表示可能的用户位置交互的最小方位角偏移值，取-180~+180，其中 b14 为符号位，“1”表示负数，“0”表示正数，b13-b6 表示度数，b5-b0 表示角分
positionInteractionRangeAzimuthMax	15 比特，表示可能的用户位置交互的最大方位角偏移值，取-180~+180，其中 b14 为符号位，“1”表示负数，“0”表示正数，b13-b6 表示度数，b5-b0 表示角分
positionInteractionRangeElevationMin	14 比特，表示可能的用户位置交互的最小高度偏移值，取-90~+90，其中 b13 为符号位，“1”表示负数，“0”表示正数，b12-b6 表示度数，b5-b0 表示角分
positionInteractionRangeElevationMax	14 比特，表示可能的用户位置交互的最大高度偏移值，取-90~+90，其中 b13 为符号位，“1”表示负数，“0”表示正数，b12-b6 表示度数，b5-b0 表示角分
positionInteractionRangeDistanceMin	7 比特，表示可能的用户位置交互的最小归一化距离，取 0-1，步长为 0.0078125
positionInteractionRangeDistanceMax	7 比特，表示可能的用户位置交互的最大归一化距离，取 0-1，步长为 0.0078125
ZoneExclusion（）	指示哪些扬声器/房间区域不渲染，指定的区域限制见表 18
minX	排除空间 X 方向的最小值，取值为-1.0~+1.0
minY	排除空间 Y 方向的最小值，取值为-1.0~+1.0
minZ	排除空间 Z 方向的最小值，取值为-1.0~+1.0
maxX	排除空间 X 方向的最大值，取值为-1.0~+1.0
maxY	排除空间 Y 方向的最小值，取值为-1.0~+1.0
maxZ	排除空间 Z 方向的最小值，取值为-1.0~+1.0

7.5 扩展元数据定义

7.5.1 概述

扩展元数据是在现有元数据基础上，不改变现有元数据结构的前提下对渲染器功能的补充，对原有元数据进行的扩展，支持环境声学 and 导演意图的表达，扩展元数据的根节点与 audioformatExtended 节点并列。

扩展元数据的层级设计跟现有元数据对应，部分语法解释见表 34：

表34 扩展元数据部分语法解释

<vrExt >	描述	示例
version	扩展元数据的版本号	0.0.1
name	扩展元数据的命名	vrExt

表34（续）

<vrExt >	描述	示例
level	扩展元数据优先级	1
presenceInfo	扩展元数据内容相关部分	
staticControl	扩展元数据的静态内容	
dynamicControl	扩展元数据的动态内容	

7.5.2 相关规范

presenceInfo 是内容相关的扩展元数据，见表 35 和 36。instance 与 audioChannelFormat 对应，目的在于在不修改 ADM 的情况下可以修改元数据内容。

表35 presenceInfo属性

属性	描述	规范
descriptor	对 presenceInfo 的描述	32 个字符以内
sampleRate	音频的采样率	整形，例如 44100

表36 presenceInfo子元素

子元素	描述	规范	必选/可选
audioProgrammeReferID	与 ADM 中的 AudioProgramme 关联	APR_1001	必选
instanceReferID	与 ADM 中 AudioChannelFormat 关联	INS_00010001	必选
isEncoded	标识是否为编码过程	0/1	可选
avdataAligned	是否与视频帧对齐	0/1	可选
frameRate	帧率，用于视频同步	Int	可选
mergeMode	是否覆盖与 ADM 相关部分，0 丢弃，1 覆盖	0/1	必选
loudnessGain	响度线性增益	0-16	可选

instance 相关规范见表 37 和 38。

表37 instance属性

属性	描述	规范
id	唯一标识该 instance	INS_0001_0001
typeLabel	对应的音频类型码	支持 0001, 0003, 0004 三种类型，取值见表 15，更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 10
typeDefinition	对应的音频类型名称	支持 DirectSpeakers, Objects, HOA，取值见表 15，更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 10

表38 instance子元素

子元素	描述	规范
audioChannelFormatRefID	与 ADM 元素匹配的 ID 匹配	AC_00010001
unitInfo	对应 audioBlockFormat，可以有多个	

unitInfo 相关规范见表 39-42。

表39 unitInfo属性

属性	描述	规范
id	唯一标识该 unit	UNI_00010001
start	该 unit 的起始时间，Objects 类型有效，格式为 hh:mm:ss.zzzzz，见注 5	typeDefinition 为 Objects 才有
duration	该 unit 的持续时长，Objects 类型有效，格式为 hh:mm:ss.zzzzz，见注 5	typeDefinition 为 Objects 才有

当 typeLabel==DirectSpeakers 时，unitInfo 相关规范见表 40。

表40 typeLabel==DirectSpeakers时unitInfo子元素

子元素	描述	单位	规范
speakerLabel	扬声器布局	-	参考 GY/T 316 扬声器布局规范
azimuth	水平角	度	-180-180
elevation	高度角	度	-90~90
distance	距离	米	0-50
gain	线性增益	-	0-16

当 typeLabel==Objects 时，unit 的子元素与 DirectSpeakers 类似，区别的是可以包含多个 unit，unitInfo 相关规范见表 41。

表41 typeLabel==Objects时unitInfo子元素

子元素	描述	单位	规范
azimuth	水平角，单位度	度	-180-180
elevation	高度角，单位度	度	-90~90
distance	距离，单位米	米	0-50
gain	线性增益	-	0-16

当 typeLabel==HOA 时，unitInfo 相关规范见表 42。

表42 typeLabel==HOA时unitInfo子元素

子元素	描述	规范
order	对应通道的 order	0-7
degree	对应通道的角度	-7~+7
normalization	归一化方式	{0,1...}
gain	线性增益	0-16

staticControl 相关规范见表 43。

staticControl 中的内容旨在控制渲染器的行为，主要为实现环境声学 and 导演意图，以及设备相关。其中的元数据是在渲染过程或码流传输中不用实时更新的数据。做为扩展元数据，我们希望所有的非实时性扩展元数据都以此作为容器和入口。

表43 staticControl子元素

子元素	描述	规范
ambisonicOrder	球谐编码阶数	1-7
acousticEnv	声学环境相关	
rendererInfo	渲染相关后处理	

acousticEnv 相关规范见表 44。

表44 acousticEnv子元素

子元素	描述	规范
type	环境声学类型	{0, 1, 2}
typeLabel	环境声学类型标签	{Physical / Artificial / Sample}
earlyReflectionGain	早期反射增益	[0.0-1.0]
lateReverbGain	后期混响增益	[0.0-1.0]
lowFreqProFlag	低频分离处理	0/1，低频可选做或不做混响处理
convolutionReverbType	采样（卷积）混响类型	{0, 1, 2...}
surface	几何空间的反射面	支持无限多个反射面组成的空间模型

surface 相关规范见表 45。

表45 surface子元素

子元素	描述	规范
material	声学环境中的材质类型，支持 25 种材质，参见附录 P	{0, 1,2...24}
materialLabel	声学环境中的材质类型标签	{brick, water...}
vertex	几何模型顶点，三个点组成一个三角形，支持无限多个三角形	[x1, y1, z1], [x2, y2, z2]...

表45 （续）

子元素	描述	规范
indices	组成三角形的顶点索引	[0, 1, 2], [1, 2, 3]...
absorption	不同频带的吸收率，需要 8 个， 可选	[0.0-1.0]，可选
scattering	不同频带的吸收率，需要 8 个， 可选	[0.0-1.0] ， 可选

material 和 materialLabel 指示的是 surface 对应的材料，不同的材料有不同的散射率和吸收率，会产生不同的动态混响。此外，还支持自定义 surface 的材料，当未指定 surface 或 surface 不在上面 material 的里表中时，以自定义 absorption 和 scattering 为主。

rendererInfo 相关规范见表 46。

表46 rendererInfo子元素

子元素	描述	规范
targetDevice	回放设备的类型	3 比特，表示制作意图，回放设备的种类，{0, 1, 2...} ‘0’：耳机，‘1’：扬声器，其他：自定义
hrtfType	hrtf 类型	4 比特，表示头相关传输函数类型，{0, 1, 2...} ‘0’：符合 SOFA 格式的 THK，‘1’：符合 SOFA 格式的 MIT，‘2’：符合 SOFA 格式的 SADIE，‘3’：符合 SOFA 格式的 CIPIC，‘4’：符合 SOFA 格式的 HUTUBS，其他：自定义
headphoneType	耳机型号	表示监听耳机型号，用 ASCII 码表示，长度在 16 个字符以内，例如：“ABCD...”，表示监听耳机型号的字符串。字符长度根据耳机型号确定。
audioEffect	后处理音效	可选

audioEffect 相关规范见表 47。

表47 audioEffect子元素

子元素	描述	规范
EQ	EQ 后处理	
DRC	DRC 后处理	
Gain	增益后处理	

EQ 相关规范见表 48。

表48 EQ属性

属性	描述	规范
index	表示音效链路的顺序	{0, 1, 2...}

EQ 由多段 item 子元素组成，item 属性规范见表 49。

表49 item属性规范

item 属性	描述	规范
type	滤波器类型	{0, 1, 2...}
typeLabel	滤波器类型标签	{lowpass, highpass, bandpass...}
frequency	截止频率	20-16000Hz
gain	增益	[-40,-40]dB
Q	品质因子	0.1-12

EQ 类型见表 50。

表50 EQ类型

类型	类型标签
0	LowPass
1	HighPass
2	BandPass
3	BandReject
4	AllPass
5	LowShelving
6	HighShelving
7	Peaking

DRC 相关规范见表 51。

表51 DRC属性

属性	描述	规范	单位
index	表示音效链路的顺序	{0, 1, 2...}	-
attackTime	开始时间	[0-100]	ms
releaseTime	释放时间	[50-300]	ms
threshold	门限值	[-80, 10]	dB
preGain	前置增益	[-10, 10]	dB
postGain	后置增益	[0, 20]	dB
ratio	压缩率	1-100	

Gain 相关规范见表 52。

表52 Gain属性

属性	描述	规范
index	表示音效链路的顺序	{0, 1, 2...}
gain	增益	-20~20dB

dynamicControl 相关规范见表 53。

dynamicControl 包含渲染过程需要实时更新的所有元数据，例如听者的 3DoF 和 6DoF 信息。作为实时性元数据的容器，所有的实时性扩展元数据都宜以此作为容器和入口。

表53 dynamicControl子元素

子元素	描述	规范
listener	头部追踪 3oF、6DoF 信息，以端上头部追踪数据为主，端上无头部追踪设备时以元数作为默认头部追踪设置	见表 54

listener 相关规范见表 54。

表54 listener子元素

子元素	描述	规范
interpolatedType	坐标插值方式	0 表示线性插值，1 表示其他插值方式。默认为 0，可选
coordinate	listener 的坐标位置	见表 55

coordinate 相关规范见表 55。

表55 coordinate子元素

子元素	描述	规范
start	相对父元素的起始时间，格式为 hh:mm:ss.zzzzz，见注 5	必选
duration	相对 start 的持续时长，格式为 hh:mm:ss.zzzzz，见注 5	必选
x	听者在世界坐标系下的位置在 x 轴上的值	三维坐标系内任意有效位置
y	听者在世界坐标系下的位置在 y 轴上的值	三维坐标系内任意有效位置
z	听者在世界坐标系下的位置在 z 轴上的值	三维坐标系内任意有效位置
front_x	指向听者面部朝向在 x 轴上的分量	三维坐标系内任意有效位置
front_y	指向听者面部朝向在 y 轴上的分量	三维坐标系内任意有效位置
front_z	指向听者面部朝向在 z 轴上的分量	三维坐标系内任意有效位置
up_x	指向听者头顶朝向在 x 轴上的分量	三维坐标系内任意有效位置

表55 （续）

子元素	描述	规范
up_y	指向听者头顶朝向在 y 轴上的分量	三维坐标系内任意有效位置
up_z	指向听者头顶朝向在 z 轴上的分量	三维坐标系内任意有效位置

如表 54 和表 55 所述，listener 用于表达听者的 3DoF 和 6DoF 信息，由一个或多个 coordinate 组成，多个 coordinate 之前有开始时间和持续时间控制衔接，coordinate 共有 9 个实时性参数，其中 (x,y,z) 是听者的位置移动，属于 6DoF 参数，(front_x,front_y,front_z) 和 (up_x,up_y,up_z) 是听者的头部姿态，属于 3DoF 参数。3DoF 和 6DoF 属于可选参数，也可以二者选一，仅支持其中的一个。

完整的扩展元数据示例代码参见附录 Q。

7.5.3 surface 的使用

由扩展元数据中的 surface 组成三维几何空间，用于模拟听者所处空间的环境声学，其中，vertex 是几何模型的顶点数组，排列方式如[x1, y1, z1, x2, y2, z2...], indices 是由顶点组成三角形的顶点索引组合，例如[0, 1, 2, 1, 2, 3...], 其中 indices[0, 1, 2]三个点组成一个三角形，对应 vertex 中的三个顶点[x1, y1, z1, x2, y2, z2, x3, y3, z3]。鞋盒模型的顶点和索引示例如图 4:

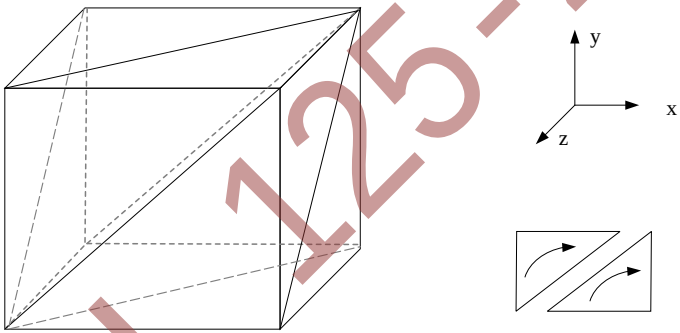


图4 鞋盒模型的顶点和索引示意图

图 4 所示为立方体鞋盒模型，有 8 个顶点，6 个面，按照上图中的方式将鞋盒模型的 6 个表面拆分为 12 个三角形，每个三角形有 3 个顶点组成，顶点的排布方式按照右手定则法线朝向听者一侧，听者位于立方体的中心，形成的三维几何模型就有 8 个顶点，12 个三角新索引组合，示例代码如下：（这块示例代码可以删掉，详见附录 Q 扩展原始局示例代码）

```
<surface>
  <vertex x="2" y="-2" z="-2"/>
  <vertex x="-2" y="-2" z="-2"/>
  <vertex x="-2" y="-2" z="2"/>
  <vertex x="2" y="-2" z="2"/>
  <vertex x="2" y="2" z="-2"/>
  <vertex x="-2" y="2" z="-2"/>
  <vertex x="-2" y="2" z="2"/>
  <vertex x="2" y="2" z="2"/>
  <indice index1="0" index2="1" index3="2"/>
```

```
<indice index1="0" index2="2" index3="3"/>
<indice index1="1" index2="5" index3="6"/>
<indice index1="1" index2="6" index3="2"/>
<indice index1="5" index2="4" index3="7"/>
<indice index1="5" index2="7" index3="6"/>
<indice index1="4" index2="0" index3="3"/>
<indice index1="4" index2="3" index3="7"/>
<indice index1="0" index2="4" index3="5"/>
<indice index1="0" index2="5" index3="1"/>
<indice index1="3" index2="2" index3="6"/>
<indice index1="3" index2="6" index3="7"/>
< /surface >
```

7.6 扩展元数据语法

扩展元数据语法见表56。

表56 扩展元数据语法

语法	比特数	助记符
vrExt () {		
name;	32 × 8	uimsbf
version;	12	uimsbf
vrExtLevel;	3	uimsbf
hasPresenceInfo	1	bslbf
hasStaticControl;	1	bslbf
hasDynamicControl	1	bslbf
if (hasPresenceInfo) {		
presenceInfo () ;		
}		
if (hasStaticControl) {		
staticControl () ;		
}		
if (hasDynamicControl) {		
dynamicControl () ;		
}		
}		

状态信息的语法见表 57。

表57 状态信息语法

语法	比特数	助记符
presenceInfo () {		
descriptor;	16 × 8	uimsbf
sampleRate;	4	uimsbf

表57（续）

语法	比特数	助记符
isEncoded;	1	bslbf
avdataAligned;	1	bslbf
frameRate;	4	uimsbf
loudnessGain;	6	uimsbf
mergeMode;	1	bslbf
if (mergeMode == 1) {		
audioProgrammeRefID;	8 × 8	uimsbf
numInstance;	7	uimsbf
for (int i = 0; i < numInstance; ++i) {		
instance[i];		
}		
}		
}		

实例语法见表 58。

表58 实例语法

语法	比特数	助记符
instance () {		
instacneID;	11 × 8	uimsbf
typeLabel;	3	uimsbf
audioChannelFormatRefID;	4	uimsbf
loudnessGain	8	uimsbf
numUnitInfo;	16	
for (int i = 0; i < numInstance; ++i) {		
unitInfo[i];		
}		
}		

单元信息语法见表 59。

表59 单元信息语法

语法	比特数	助记符
unitInfo () {		
unitInfoID;	12 × 8	uimsbf
gain;	8	uimsbf
if (typeLabel == 0001) {		
speakerLabel;	4	uimsbf

表 59 （续）

} else if （typeLabel == 0003） {		
azimuth;	15	uimsbf
elevation;	14	uimsbf
diatance;	7	uimsbf
} else if （typeLabel == 0004） {		
order;	3	uimsbf
degree;	4	uimsbf
normlize;	2	uimsbf
}		
}		

静态控制语法见表 60。

表60 静态控制语法

语法	比特数	助记符
staticControl () {		
hasAcousticEnv;	1	bslbf
hasRenderInfo;	1	bslbf
ambisonicOrder;	3	uimsbf
if （hasAcousticEnv） {		
acousticEnv () ;		
}		
if （hasRenderInfo） {		
renderInfo () ;		
}		
}		

环境声学语法见表 61。

表61 环境声学语法

语法	比特数	助记符
acousticEnv () {		
hasEarlyReflectionGain;	1	bslbf
hasLateReverbGain;	1	bslbf
reverbType;	2	uimsbf
if （hasEarlyReflectionGain） {		
earlyReflectionGain;	8	uimsbf
}		
if （hasLateReverbGain） {		
lateReverbGain;	8	uimsbf
}		

表61（续）

语法	比特数	助记符
}		
if (reverbType == 2) {		
convolutionReverbType;	5	uimsbf
}		
numSurface;	5	uimsbf
for (i = 0; i < numSurface; i++) {		
surface ();		
}		
}		

表面语法见表 62。

表62 表面语法

语法	比特数	助记符
surface () {		
material;	5	uimsbf
if (material == 0x1f) {		
for (i = 0; i < 8; i++) {		
absorption[i];	10	uimsbf
scattering[i];	10	uimsbf
}		
}		
numVertices;	10	uimsbf
for (i = 0; i < numVertices; i++) {		
vertex ();		
}		
numIndices;	10	uimsbf
for (i = 0; i < numIndices; i++) {		
indices ();		
}		
}		

顶点语法见表 63。

表63 顶点语法

语法	比特数	助记符
vertex () {		

表63 （续）

语法	比特数	助记符
x;	14	uimsbf
y;	14	uimsbf
z;	14	uimsbf
}		

索引语法见表 64。

表64 索引语法

语法	比特数	助记符
indices () {		
idnex1;	10	uimsbf
index2;	10	uimsbf
index3;	10	uimsbf
}		

渲染信息语法见表 65。

表65 渲染信息语法

语法	比特数	助记符
renderInfo () {		
targetDevice;	3	uimsbf
hrtfType;	4	uimsbf
headphoneType;	16×8	uimsbf
audioEffect () ;		
}		

音效语法见表 66。

表66 音效语法

语法	比特数	助记符
audioEffect () {		
isEQExist;	1	bslbf
isDRCEexist;	1	bslbf
isGainExist;	1	bslbf
if (isEQExist isDRCEexist isGainExist) {		
effectChain;	3	uimsbf
}		
if (isEQExist) {		
numEqband	4	uimsbf
for (i= 0; i < numEqband; i++) {		

表66 （续）

语法	比特数	助记符
eqEffect () ;		
}		
}		
if (isDRCExist) {		
attackTime;	8	uimsbf
releaseTime;	8	uimsbf
threshold;	9	uimsbf
preGain;	9	uimsbf
postGain;	9	uimsbf
ratio;	8	uimsbf
}		
if (isGainExist) {		
effectGain;	9	uimsbf
}		
}		
}		

均衡器语法见表 67。

表67 均衡器语法

语法	比特数	助记符
eqEffect () {		
eqType;	3	uimsbf
eqFc;	15	uimsbf
eqQQFlag;	1	uimsbf
eqQ;	7	uimsbf
eqGain;	9	uimsbf
}		

动态控制语法见表 68。

表68 动态控制语法

语法	比特数	助记符
dynamicControl () {		
hasListener;	1	bslbf
if (hasListener) {		
listenerInfo () ;		
}		
}		

听着信息语法见表 69。

表69 听者信息语法

语法	比特数	助记符
listenerInfo () {		
interpolatedType;	1	uimsbf
numListenerPos;	8	uimsbf
for (int i = 0; i < numListenerPos; ++i) {		
listenerPosition () ;		
}		
}		

听者位置语法见表 70。

表70 听者位置语法

语法	比特数	助记符
listenerPosition () {		
start;	27	uimsbf
duration;	27	uimsbf
x;	15	uimsbf
y;	15	uimsbf
z;	15	uimsbf
front_x;	7	uimsbf
front_y;	7	uimsbf
front_z;	7	uimsbf
up_x;	7	uimsbf
up_y;	7	uimsbf
up_z;	7	uimsbf
}		

7.7 扩展元数据语义

扩展元数据的语义见表71。

表71 扩展元数据的语义

名称	语义
vrExt ()	扩展元数据接口，规范请参考表 57
name	32 字符，描述 vrExt 扩展元数据的名字
version	12 比特，vrExt 的版本号，例如 1.1.1，每一段 4 个比特，最大为 10，最大版本号可表示到 10.10.10
vrExtLevel	3 比特，vrExt 分层数，取 1-4
hasPresenceInfo	1 比特，表示 vrExt 中是否存在 presenceInfo，‘0’：不存在，‘1’：存在

表71 （续）

名称	语义
hasStaticControl	1 比特：表示 vrExt 中是否存在 staticControl，‘0’：不存在，‘1’：存在
hasDynamicControl	1 比特，表示 vrExt 中是否存在 dynamicControl，‘0’：不存在，‘1’：存在
presenceInfo ()	用于重新定义基础元数据的内容，在不修改基础元数据的前提下完成音频内容表达的更新
descriptor	16 字符，对 presenceInfo 的描述
sampleRate	4 比特，音频采样率的描述， ‘0’：8000Hz ‘1’：16000Hz ‘2’：24000Hz ‘3’：32000Hz ‘4’：44100Hz ‘5’：48000Hz ‘6’：96000Hz ‘7-16’：保留
isEncoded	1 比特，表示是否为编码后的码流，‘0’：否，‘1’：是
avdataAligned	1 比特，表示是否需要和视频帧对齐，‘0’：不对齐，‘1’：对齐
frameRate	4 比特，表示视频帧率，在 avdataAligned 为 1 时使用，‘0’：30 frames/sec， ‘1’：60 frames/sec，‘2’：90 frames/sec，‘4’：120 frames/sec
loudnessGain	8 比特，表示响度增益，取 0-16，步长为 0.0625
mergeMode	1 比特，表示是否覆盖与 ADM 相关部分，0 丢弃，1 覆盖
audioProgrammeRefID	8 字符，和基础元数据 audioProgrammeRefID 对应，表示替换该节目下的基础元数据
numInstance	7 比特，Instance 的数目
instance ()	覆盖基础元数据的内容，和 audioChannelFormat 对应
instacneID	11 字符，Instance 的唯一索引，和 audioChannelFormatID 对应
typeLabel	3 比特，表示 Instance 对应的元数据类型，取值见表 15，更多取值可参考 ITU-R BS.2076-2 音频定义模型中表 10
audioChannelFormatRefID	11 字符，对应的 audioChannelFormat 唯一索引，用于查找该音频通道
numUnitInfo	16 比特，unitInfo 的个数
unitInfo ()	instance 的实际内容承载结构
unitInfoID	12 字符，unitInfo 的唯一索引，和 audioblockFormatID 一致，用于替换对应的 audioBlockFormat 内容
speakerLabel	4 比特，当 typeLabel 值为 0001 时使用，取值参考表 12
gain	8 比特，unitInfo 对应的音频增益
azimuth	15 比特，unitInfo 的水平角，取-180~+180，其中 b14 为符号位，“1”表示负数，“0”表示正数，b13-b6 表示度数，b5-b0 表示角分
elevation	14 比特，unitInfo 的高度角，取-90~+90，其中 b13 为符号位，“1”表示负数，“0”表示正数，b12-b6 表示度数，b5-b0 表示角分
diatance	7 比特，unitInfo 的归一化距离，取 0-1，步长为 0.0078125
order	3 比特，HOA 通道的阶数，取 0-7

表71 （续）

名称	语义
degree	4 比特，HOA 通道的度数，取-order~+order
normlize	2 比特，HOA 通道的归一化方式，‘0’：SN3D，‘1’：N3D，‘2’：FuMa，默认为 0
staticControl（）	静态控制，包含渲染器一开始就需要的扩展元数据，包括环境声学部分和导演意图设定
hasAcousticEnv	1 比特，表示 staticControl 里是否存在 acousticEnv 字段，‘0’：不存在，‘1’：存在
hasRenderInfo	1 比特，表示 staticControl 里是否存在 renderInfo 字段，‘0’：不存在，‘1’：存在
ambisonicOrder	3 比特，表示球谐编码阶数，渲染器使用
acousticEnv（）	声学环境元数据接口
hasEarlyReflectionGain	1 比特，表示 AcousticEnv 里是否存在 earlyReflectionGain 字段，‘0’：不存在，‘1’：存在
hasLateReverbGain	1 比特，表示 AcousticEnv 里是否存在 lateReverbGain 字段，‘0’：不存在，‘1’：存在
reverbType	2 比特，表示声学环境模型类型，‘0’：“Physical（物理混响）”，‘1’：“Artificial（人工混响）”，‘2’：“Sampling（采样卷积混响）”，‘3’：“扩展类型”
earlyReflectionGain	8 比特，表示早期反射增益，取 0-16.0，步长为 0.0625
lateReverbGain	8 比特，表示晚期反射增益，取 0-16.0，步长为 0.0625
convolutionReverbType	5 比特，表示采样（卷积）混响类型，{0,1,2...N}，例如：‘0’：音乐厅采样卷积混响，‘1’：录音棚采样卷积混响，...。
numSurface	5 比特，表示 acousticEnv（）里包含的 surface（）个数，取值为{0,1,2,3,4,5...}
surface（）	同种材质墙面元数据接口
material	5 比特，表示声学环境中的材质种类，vertex 的子元素，{0,1,...,31}，支持 32 种材质，例如：brick、water，不同的材质有不同的散射率和吸收率。取值参考表 38。31 代表自定义材质
absorption	10 比特，表示某一频带的吸收率，取 0-1.00，步长为 0.001
scattering	10 比特，表示散射率，取 0-1.00，步长为 0.001
numVertices	10 比特，表示 Surface 里包含的 Vertex 个数
vertex（）	同一几何材质表面组成的三角形顶点坐标，其坐标 x，y，z 分别为 14 比特，取值为 0-100，其中 7 比特表示米数，7 比特表示厘米数
numIndices	10 比特，表示组成 Surface 里包含的顶点个数
indices（）	表示组成 Surface 里包含的顶点组合，其做索引值为 10 比特，取 0-1000
renderInfo（）	后期效果处理元数据解码接口
targetDevice	3 比特，表示制作意图，回放设备的种类。‘0’：耳机，‘1’：扬声器，其他：保留

表71 （续）

名称	语义
hrtfType	4 比特，表示符合 SOFA 标准的头相关传输函数数据，{0,1,...,5}索引分别对应[THK, MIT, SADIE, CIPIC, HUTUBS, 自定义]
headphoneType	7 比特，表示监听耳机类型，“ABCD...”，表示监听耳机型号的字符串
audioEffect ()	EQ (Equalizer)、DRC (Dynamic Range Control) 等后期处理元数据接口
isEQExist	1 比特，表示 AudioEffect 里是否存在 EQ 字段，‘0’：不存在，‘1’：存在
isDRCExist	1 比特，表示 AudioEffect 里是否存在 DRC 字段，‘0’：不存在，‘1’：存在
isGainExist	1 比特，表示 AudioEffect 里是否存在 Gain 字段，‘0’：不存在，‘1’：存在
effectChain	3 比特，表示 EQ、DRC、Gain 执行顺序， ‘0’： Gain→EQ→DRC ‘1’： Gain→DRC→EQ ‘2’： EQ→DRC→Gain ‘3’： EQ→Gain→DRC ‘4’： DRC→EQ→Gain ‘5’： DRC→Gain→EQ
numEqband	4 比特，表示 AudioEffect () 里包含的 eqEffect 个数，‘0’-‘11’：表示 AudioEffect () 里包含的 eqEffect 个数，‘12’-‘15’：保留
eqEffect ()	EQ 属性效果参数接口
eqType	3 比特，表示 EQ 的类型
eqFc	15 比特，表示滤波器截止频率，取 20-20000
eqQ	7 比特，表示品质因子，取 0-4，步长为 0.03125
eqGain	9 比特，表示 EQ 的增益，取-32~+32，步长为 0.125，其中，最高位为符号位，‘0’表示正数，‘1’表示负数
attackTime	8 比特，表示 DRC 触发时间
releaseTime	8 比特，表示 DRC 释放时间
threshold	9 比特，表示 DRC 触发门限
preGain	9 比特，表示 DRC 前置增益
postGain	9 比特，表示 DRC 后置增益
ratio	8 比特，表示 DRC 压缩率
effectGain	9 比特，表示预增益
dynamicControl ()	动态扩展元数据，包含听者的 3DoF、6DoF 信息
hasListener	1 比特，表示 dynamicControl 是否存在听者信息
listenerInfo ()	听者的 3DoF 和 6DoF 信息
interpolatedType	1 比特，听者信息插值方式，‘0’：线性插值，‘1’：非线性插值
numListenerPos	8 比特，听者位置参数的个数

表71 （续）

名称	语义
listenerPosition（）	当用户无头戴设备时使用该数据作为头部追踪数据
start	27 比特，听者位置参数开始时间，如 00 时：00 分：12 秒：300 毫秒，其中 5 比特表示小时，6 比特表示分钟，6 比特表示秒数，10 比特表示毫秒
duration	27 比特，听者位置参数持续时长，如 00 时：00 分：12 秒：300 毫秒，其中 5 比特表示小时，6 比特表示分钟，6 比特表示秒数，10 比特表示毫秒
x	15 比特，听者位置的 x 坐标，取-100.00~100.00，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数，b13-b7 表示米数，b6-b0 表示厘米数
y	15 比特，听者位置 y 坐标，取-100.00~100.00，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数，b13-b7 表示米数，b6-b0 表示厘米数
z	15 比特，听者位置的 z 坐标，取-100.00~100.00，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数，b13-b7 表示米数，b6-b0 表示厘米数
font_x	7 比特，听者面部朝向的 x 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数
front_y	7 比特，听者面部朝向的 y 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数
front_z	7 比特，听者面部朝向的 z 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数
up_x	7 比特，听者头顶朝向的 x 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数
up_y	7 比特，听者头顶朝向的 y 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数
up_z	7 比特，听者头顶朝向的 z 坐标，取-1~1，步长为 0.015625，其中最高位 b14 为符号位，‘0’表示正数，‘1’表示负数

8 AAMSF 封装格式

8.1 概述

针对 VR 音频制作的特点和元数据传输需求，制定音频元数据串行流封装格式，即 AVS 音频元数据串行格式 AAMSF，包括头信息、制作者签名和音频元数据块。串行流文件扩展名为.saam（sequential AVS audio metadata），制作者签名和元数据块的存储文件格式可以是.xml 或.json。

8.2 AAMSF 语法

表 72 规定了 AVS 音频元数据串行流格式 AAMSF 的语法结构 aamsfSequence（），表 73 规定了 AAMSF 序列的头信息语法结构 aamsfHeader（），表 74 规定了制作者签名信息语法结构 productionInfoBlock（），元数据块语法结构 metadataBlock（）见第 6 章。

表72 aamsfSequence () 语法

语法	比特数	助记符
aamsfSequence ()		
{		
aamsfHeader () ;		
numofBlocks	3	uimsbf
for (i = 0; i < numofBlocks; i++) {		
if (productionInfoPresent) {		
productionInfoBlock () ;		
}		
if (metadataPresent) {		
metadataStreamLength	32	uimsbf
metadataBlock () ;		
}		
if (renderPresent) {		
rendererMode	8	uimsbf
}		
}		
};		

表73 aamsfHeader () 语法

语法	比特数	助记符
aamsfHeader ()		
{		
aamsfId;	40	bslbf
aamsfFlag	8	bslbf
};		

表74 productionInfoBlock () 语法

语法	比特数	助记符
productionInfoBlock ()		
{		
Title	32×8	bslbf
countryCode	3×8	bslbf
Composer	32×8	bslbf
Recorder	32×8	bslbf
Mixer	32×8	bslbf
soundEditor	32×8	bslbf

表74 （续）

语法	比特数	助记符
finalmixStage	32×8	bslbf
timestampFormat	2	bslbf
Duration	32	bslbf
Comment	32×8	bslbf
}		

8.3 AAMSF 语义

AAMSF的语义见表75。

表75 AAMSF的语义

名称	语义
aamsfSequence（）	AAMSF流
aamsfHeader（）	AAMSF序列的头信息
metadataBlock（）	AVS VR音频元数据流格式，见第6章
aamsfId	5字节，AAMSF的ID，其ASCII的值为” AAMSF”
aamsfFlag	8比特 AAMSF的信息块索引 ——b0 productionInfoPresent ’ 1’ 包含AVS VR音频制作基本信息 ’ 0’ 不包含AVS VR音频制作基本信息 ——b1 metadataPresent ’ 1’ 仅包含动态元数据信息 ’ 0’ 所有（包含静态和动态）元数据信息 ——b2 renderPresent ’ 1’ 包含AVS VR音频渲染信息 ’ 0’ 不包含AVS VR音频渲染信息 ——b3, b4, b5, b6, b7保留，默认值为’ 0’
numofBlocks	3比特，元数据块的数量
metadataStreamLength	32比特，以字节为单位表示的元数据块的数据长度
rendererMode	8 比特，渲染器模式选择 0x00~0x7F 面向耳机输出的渲染器 0x00 双耳渲染模式1（ID1），见第9章 0x80~0xFF 面向扬声器输出的渲染器 0x80 扬声器渲染模式（ID2），见第10章
productionInfoBlock（）	AVS VR音频制作基本信息，包括名称，制作人，注释等。
title	32字节，名称
countryCode	3字节，出版国家，依据ISO 3166-1规定的3字节国家码
composer	32字节，制作人
recorder	32字节，录音师
mixer	32字节，混音师

表75 （续）

名称	语义
soundEditor	32字节，声音编辑师
finalmixStage	32字节，终混棚/工作室名称
timestampFormat	2 比特，计时单位 ‘0’ 用音频帧表示 ‘1’ 用毫秒表示 ‘2’，‘3’保留
duration	32比特，时长
comment	32字节，注释

应用示例参见附录N。

9 耳机渲染器

9.1 渲染器（ID1）系统框架

面向双耳耳机输出的基于Ambisonics的渲染器ID1的处理过程包含元数据处理过程和核心渲染过程：元数据处理过程中存在描述音频内容和渲染技术的控制信息，比如音频载荷的输入形式是单通道、双声道、多声道，还是Object或者声场HOA，以及动态的声源和听者的位置信息，渲染的声学环境信息如房屋形状，大小，墙体材质等。核心渲染过程依据不同的音频信号表示形式和从元数据模型中解析出来的相应Metadata，做相应播放设备和环境的渲染。系统框架如图5所示：

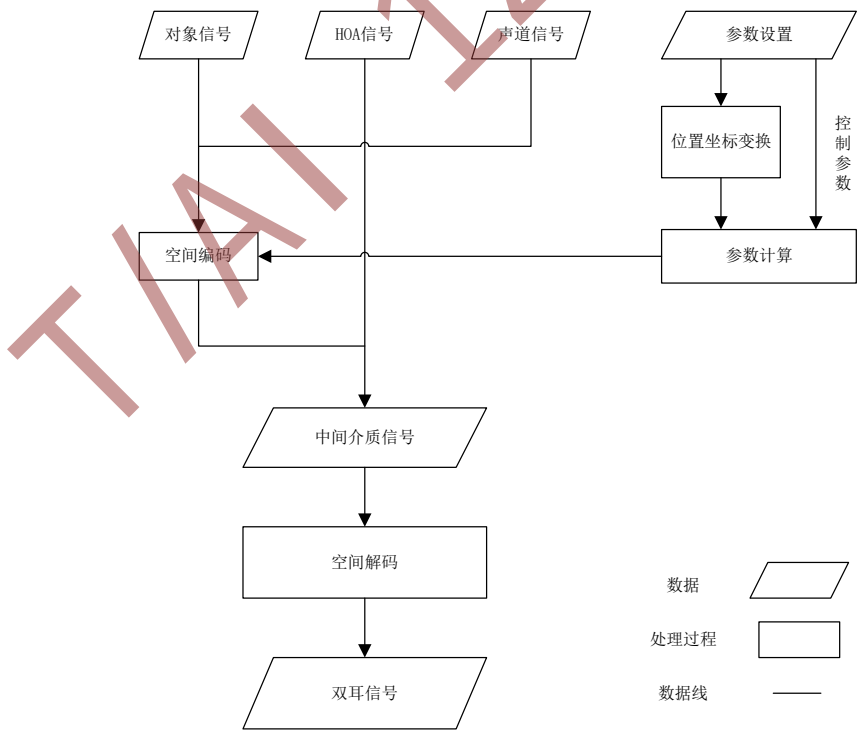


图5 渲染器 ID1 总体框架

图6是渲染器ID1的分模块流程图，主要包含元数据的解析和转换，以及核心渲染引擎两部分，支持两种输入方式：PCM和编码码流，两种码流可以通过<audioformatExtended>中的formatLabel/formatDefinition或者<vrExt>中的isEncoded来区分。前者可以用在渲染器独立工作的场景，后者用在码流编解码的完整系统中。从<audioformatExtended>和<vrExt>拼装出完整的音频元数据，封装在Metadata结构中通过渲染控制器传递给核心渲染引擎完成相应音频的渲染。渲染器ID1具体技术的原理参见附录R。

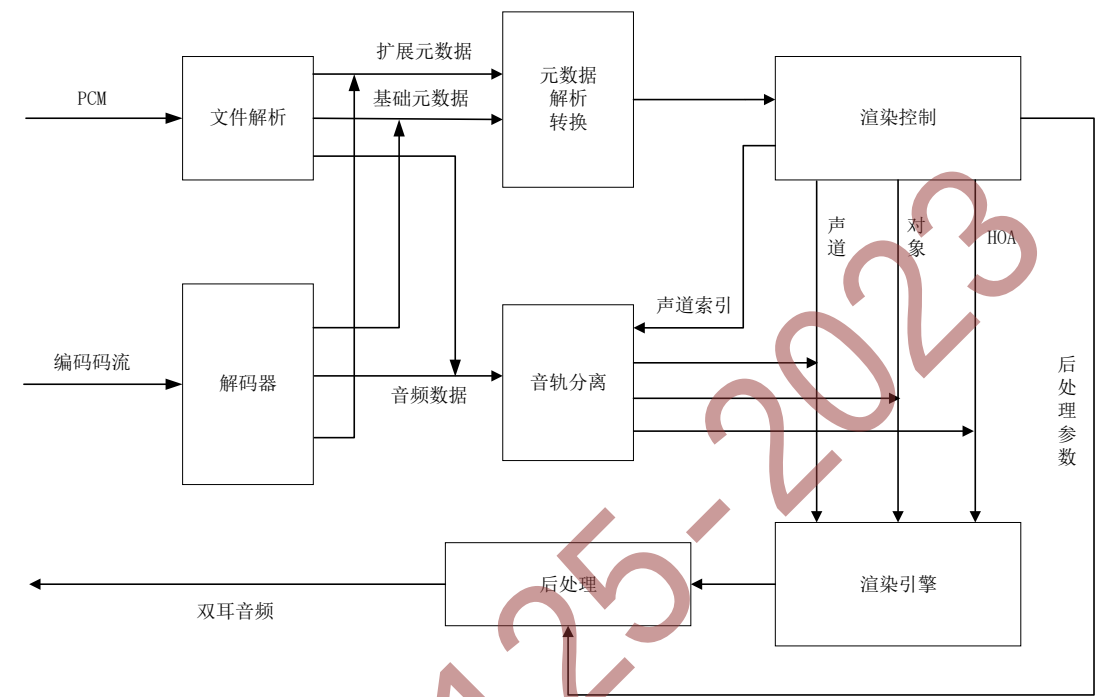


图6 渲染系统 ID1 数据流图

9.2 渲染器 ID1 框架语法

耳机渲染语法见表76。

表76 耳机渲染语法

语法	比特数	助记符
binauralRender ()		
{		
metadata = parseMetadata (bwf) ;		
createBinauralRenderer (metadata) ;		
for (int i = 0; i <= sampleNum; i += kblockSize) {		
setListenerPostion (x, y, z) ;	8×3	bslbf
if (type == Directspeakers)		
{		
submitMCBuffer () ;		
}		
if (type == Objects)		
{		

表76 （续）

语法	比特数	助记符
setObjectPosition (x, y, z) ;	8×3	bslbf
submitObjBuffer () ;		
}		
if (type == HOA)		
{		
submitHOABuffer () ;		
}		
}		
getBinauralAudioBuffer () ;		
}		

解析元数据语法见表77。

表77 解析元数据语法

语法	比特数	助记符
parseMetadata (bwf)		
{		
bw64AxmlChunk;		
bs2051Layouts;	4	uimsbf
objX;	8	uimsbf
objY;	8	uimsbf
objZ;	8	uimsbf
hoaOrder;	8	uimsbf
hoaNormlization;	2	uimsbf
interpolation () ;		
metadata;		
return metadata		
}		

创建耳机渲染器语法见表78。

表78 创建耳机渲染器语法

语法	比特数	助记符
createBinauralRenderer (metadata)		
{		
initAudioContext () ;		
if (hasChannels) {	1	uimsbf
addChannelSource (bs2051Layouts) ; 字节：和bs2051Layouts统一	4	uimsbf
}		

表78 （续）

语法	比特数	助记符
if (hasObject) {	1	uimsbf
addObjectSource (x, y, z) ;	8	bslbf
}		
if (hasHOA) {	1	uimsbf
addHOASource (order, degree) ;	8	bslbf
}		
}		

9.3 渲染器 ID1 框架语义

渲染器ID1框架的语义见表79。

表79 渲染器ID1框架的语义

名称	语义
parseMetadata ()	将 bw64 文件中的元数据解析成统一元数据封装格式，包含基础元数据和扩展元数据
interpolation ()	对象音频每个时间点位置进行插值处理
createBinauralRenderer ()	根据渲染器 ID 创建相应的渲染器，此处应使用 ID1
setObjectPosition ()	如果对象音频的位置发生改变，则调用此函数更新对象的位置，见表 84
addChannelSource ()	根据声道音频的布局添加对应的音频源
addObjectSource ()	根据对象音频的初始位置添加对应的音频源
addHOASource ()	根据 HOA 音频的格式、order、degree 添加对应的音频源
submitMCBuffer ()	对于声道类型类型的音频，使用此接口提交音频数据给渲染器，见表 86
submitObjBuffer ()	对于对象类型的音频，使用此接口提交音频数据给渲染器，见表 87
submitHOABuffer ()	对于 FOA/HOA 类型的音频，使用此接口提交音频数据给渲染器，见表 88
getBinauralAudioBuffer ()	获取渲染后的双耳输出音频，见表 86

9.4 渲染引擎语法

双耳渲染引擎基于Ambisonic的声场重建技术，主要功能是将输入音频编码为Ambisonic信号作为中间介质存在，再将中间介质信号与HRTF解码为双耳信号，其中声源移动、头部追踪和6DoF参数在Ambisonic编码阶段完成。初始化阶段需要获取AmbisonicEncoder，BinauralDecoder以及存储中间介质的缓冲区等核心要素。

初始化耳机渲染器语法见表80。

表80 初始化耳机渲染器语法 字节：补充输入（输出）及比特数

语法	比特数	助记符
initAudioContext () {		
binauralDecoder () ;		
ambisonicEncoder () ;		
ambisonicBuffer[order][frameLen];	4	uimbsf
}		

ambisonic编码语法见表81。

表81 ambisonic编码语法

语法	比特数	助记符
ambisonicEncoder () {		
lookupAmbisonicTable () {		
switch order: {	4	uimbsf
case 1:		
return hoaCoefficient1;		
case 2:		
return hoaCoefficient2;		
case 3:		
return hoaCoefficient3;		
case 4:		
return hoaCoefficient4;		
case 5:		
return hoaCoefficient5;		
case 6:		
return hoaCoefficient6;		
case 7:		
return hoaCoefficient7;		
default:		
return hoaCoefficient1;		
}		
}		
process () {		
for (int i = 0; i < channels; ++i) {		
ambisonicBuffer[i] = channelAudios[i] × hoaCoefficient;		
}		
}		
}		

双耳解码语法见表82。

表82 双耳解码语法

语法	比特数	助记符
binauralDecoder () {		
init () {		
loadHRIR () ;		
if (audioSampleRate != hrirSampleRate) {		
resampleHRIR () ;		
}		
convertHRIRToHRTF () ;		
}		
process () {		
for (int i = 0; i < channels; i++) {		
hoaBuffer[i]=abmbisonicBuffer[i]× hoaRotatorMatrix;		
}		
convolverAudioWithHRTF () ;		
for (int i = 0; i < channels; ++i) {		
if (degree >= 0) {	4	uimsbf
outLeft += channelBuffer [i]		
outRight += channelBuffer [i]		
} else {		
outLeft += channelBuffer [i]		
outRight -= channelBuffer [i]		
}		
}		
}		
}		

添加声源语法见表83。

表83 添加声源语法

语法	比特数	助记符
addSource () {		
sourceID;	8	uimsbf
}		

设置对象音频位置语法见表84。

表84 设置对象音频位置语法

语法	比特数	助记符
setObjectPosition () {		
sourcePostion;	8	bslbf
hoaRotatorMatrix;		
}		

设置听者位置语法见表85。

表85 设置听者位置语法

语法	比特数	助记符
setListenerPosition () {		
listenerPosition;	8	bslbf
hoaRotatorMatrix;		
}		

提交声道音频数据语法见表86。

表86 提交声道音频数据语法

语法	比特数	助记符
submitMCBuffer () {		
for (int i = 0; i < channels; i++) {		
ambisonicEncoder.process () ;		
}		
}		

提交对象音频位置语法见表87。

表87 提交对象音频数据语法

语法	比特数	助记符
submitObjBuffer () {		
ambisonicEncoder.process () ;		
}		

提交HOA音频数据语法见表88。

表88 提交HOA音频数据语法

语法	比特数	助记符
submitHOABuffer () {		
for (int i = 0; i < channels; i++) {		
for (int j = 0; j < sampleNum; j++) {		
addHOABuffer () ;		
}		
}		
}		

获取耳机输出音频语法见表89。

表89 获取耳机输出音频语法

语法	比特数	助记符
getBinauralAudioBuffer () {		
binauralDecoder.process () ;		
for (int i = 0; i < channels; i++) {		
for (int j = 0; j < sampleNum; j++) {		
binauralBuffer[i][j] × gain;	8	uimsbf
}		
}		
}		

9.5 渲染引擎语义

渲染引擎的语义见表90。

表90 渲染引擎的语义

名称	语义
initAudioContext ()	初始化渲染器上下文,用于创建 ambisonicEncoder 和 binauralDecoder 的实例,并创建用于保存中间状态的 ambisonicBuffer。
ambisonicEncoder ()	用于将输入音频数据编码成 Ambisonic 信号。调用 lookupAmbisonicTable () 查找当前阶数对应的 Ambisonic 系数,调用 process () 将输入音频与查找到的 Ambisonic 系数进行转化
binauralDecoder ()	用于将 Ambisonic 信号解码成双耳信号。调用 process () 将 HRTF 与保存在 ambisonicBuffer 中的数据进行卷积操作,卷积结果按照 Degree 的顺序进行加减操作,获取双耳输出音频。
hoaRotator	若输入信号是 HOA 类型,则需要根据 Listener 位置对 HOA 信号做旋转。
ambisonicBuffer	存放 Ambisonic 中介质信号。支持 1-7 阶输入
hoaCoefficientN	根据 Ambisonic 的 order 和 degree 查找 HOA 编码系数。将编码后的数据存放在 ambisonicBuffer 中
order	Ambisonic 信号的阶数,取值范围为 1-7
degree	Ambisonic 信号的度数,取值范围为-order~+order
addSource ()	根据音频类型添加音频源,可以是多声道类型、对象类型、HOA 类型
sourceID	存放和标识某一个声源,值为大于 0 的正整数
sourcePostion	声源位置信息,使用世界坐标系元数据坐标形式,例如 (x, y, z)
setListenerPosition ()	设置听者的位置信息,使用世界坐标系元数据坐标形式
listenerPosition	听者位置信息,使用世界坐标系元数据坐标形式,例如 (x, y, z)
hoaRotatorMatrix	根据声源位置和听者位置计算得到的 Ambisonic 旋转矩阵
binauralBuffer	存放输出的双耳音频,以交错格式存放,其长度在初始化的时候确定

表90 （续）

名称	语义
gain	音频增益，此处的增益为线性增益，直接作用于 binauralBuffer 上，其值可根据元数据每一帧进行调整。
submitMCBuffer ()	对于声道类型，根据每个通道的 sourceID 输入每个通道的音频数据。
submitObjBuffer ()	对于对象类型，根据对象音频的 sourceID 输入每个通道的音频数据。
submitHOABuffer ()	用于按通道输入 HOA 类型的音频数据
getBinauralAudioBuffer ()	获取双耳输出音频，此过程调用 binauralDecoder 进行 HRTF 卷积操作，并从 binauralBuffer 中获取双耳输入

9.6 6DoF 语法

设置听者6DoF位置语法见表91。

表91 设置听者6DoF位置语法

语法	比特数	助记符
setListener6DoFPosition () {		
crossFrontUp () ;		
listenerPosition;	8	uimsbf
hoaRoratorMatrix;		
}		

计算6DoF系数语法见表92。

表92 计算6DoF系数语法

语法	比特数	助记符
calculate6DoFCoefficient () {		
getRelativePosition () ;		
getRealPosition () ;		
lookupAmbisonicTable () ;		
}		

9.7 6DoF 语义

6DoF的语义见表93。

表93 6DoF的语义

名称	语义
setListener6DoFPosition ()	设置听者的 6DoF 位置，格式为符合第 6.2 节世界坐标系定义的元数据坐标。

表93 （续）

名称	语义
crossFrontUp （）	听者面部朝向和头顶朝向姿态叉乘，以获取垂直方向的完整的头部姿态。
getRelativePosition （）	计算声源和听者的相对位置。在世界坐标系中选取听者位置为参考点，使用向量减法进行计算。
getRealPosition （）	计算听者在世界坐标系中的世界位置。考虑听者头部姿态在相对坐标系中对相对位置的关系后计算最终的听者位置，该位置包含了 6DoF 信息。
lookupAmbisonicTable （）	根据听者位置计算 6DoF 场景的 HOA 编码系数，用于更新 HOA 编码

9.8 动态混响语法

提交Mesh语法见表94。

表94 提交Mesh语法

语法	比特数	助记符
submitMesh （） {		
absorption;	8	uimsbf
scattering;	8	uimsbf
vertices;	8	uimsbf
indices;	8	uimsbf
startRayTracing （） ;		
}		

更新场景语法见表95。

表95 更新场景语法

语法	比特数	助记符
updateScene （） {		
getRelativePosition （） ;		
updateRayIntensity （） ;		
laterReflectionRT60;	8	uimsbf
attenuation;	8	uimsbf
}		

获取带动态混响双耳输出语法见表96。

表96 获取带动态混响双耳输出语法

语法	比特数	助记符
getBinauralOutput （） {		
caclulateReverb （） ;		

表96 （续）

语法	比特数	助记符
for （int i = 0; i <= samples; ++i） {		
directSound[i] = directSound[i] + reverberation[i]		
}		
}		

9.9 动态混响语义

动态混响的语义见表97。

表97 动态混响的语义

名称	语义
submitMesh（）	设置听者所处场景的几何模型，该模型由 vertices 和 indices 组成，属性包括墙壁散射率和吸收率
startRayTracing（）	开始声线追踪，系统随机发射若干条声线在上述几何空间中进行反射、吸收、衰减等过程，最终有一部分声音被听者接受。
updateScene（）	实时计算听者在场景中的位置和产生的效果，当听者的 6DoF、声源的位置发生变化时，场景中的声线反射和接收方向会发生改变。
getRelativePosition（）	获取听者在世界坐标系的相对位置。当听者或声源的位置发生改变时，在相对坐标系中的听者位置会发生变化。
updateRayIntensity（）	重新计算接收到的声线强度。当有外接条件发生变化时，场景内的声线传播路径会发生变化，需要对当前环境进行重新计算。
laterReflectionRT60	环境 RT60。根据接收到声线强度计算出混响时长。
attenuation	声音在当前场景中的衰减系数。
getBinauralOutput（）	获取动态混响的双耳输出，将直达声和后期混响叠加后输出即为动态混响的双耳输出。

10 扬声器渲染器

10.1 渲染器（ID2）系统框架

面向扬声器输出的基于标准扬声器布局的空间音频渲染器（ID2）使用ADM音频模型的元数据对音频文件或音频流进行渲染处理，含元数据的音频文件以BW64格式存储，该文件包含一个<axml>块，允许携带XML格式的AMD元数据。ADM为基于对象（可简称：对象）、基于HOA（可简称：HOA）和基于声道（可简称：声道）类型的音频提供必要的元数据。

渲染器 ID2 的总体架构由图 7 所示：

其中过程如下：

- 1) 获取元数据并进行解析，得到不同类型音源的元数据；
- 2) 根据 1) 中解析后的元数据选择目标扬声器布局；

- 3) 根据 2) 中确定的扬声器布局加载对应的渲染器参数配置;
- 4) 分别使用三种渲染单元处理相应的音频信号输入;
- 5) 将 4) 中渲染后的所有音频信号输出进行增益混合, 得到最终输出。

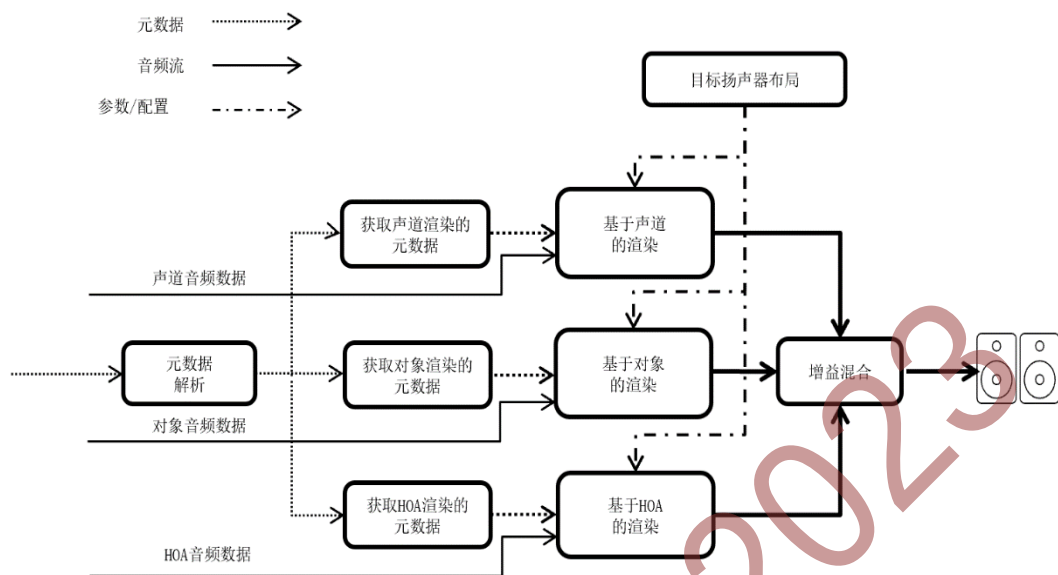


图7 渲染器 ID2 总体构架

渲染器ID2具体技术的原理参见附录S。

10.2 渲染器 ID2 框架语法

扬声器渲染的语法见表98。

表98 扬声器渲染的语法 `LoudspeakerRenderer()`

语法	比特数	助记符
loudspeakerRenderer ()		
{		
parseMetadata (bwf) ;		
typeDefinition;	2	uimsbf
switch (typeDefinition) {		
case Objects:		
getObjectsTypeMetadata () ;		
objectsRender () ;		
case DirectSpeakers:		
getDirectSpeakersTypeMetadata () ;		
directspeakersRender () ;		
case HOA:		
getHOATypeMetadata () ;		
hoaRender () ;		
}		
}		

10.3 渲染器 ID2 框架语义

渲染器ID2框架的语义见表99。

表99 渲染器ID2框架的语义

名称	语义
parseMetadata ()	见表 77
typeDefinition	输入的音频类型
getObjectsTypeMetadata ()	对象渲染器需要的元数据，见表 100
objectsRender ()	使用基于对象的渲染器，见表 101
getDirectSpeakersTypeMetadata ()	声道渲染器需要的元数据，见表 105
directspeakersRender ()	使用基于声道的渲染器，见表 106
getHOATypeMetadata ()	HOA 渲染器需要的元数据，见表 109
hoaRender ()	使用基于 HOA 的渲染器，见表 110

10.4 基于对象的渲染语法

基于对象的渲染语法涉及 metadata 元数据类型、objectsRender 对象渲染器、objectGainCalculate 增益计算、decorrelate 去相关延迟等类和库。

获取基于对象元数据类型的语法见表100。

表100 获取基于对象元数据的语法getObjectsTypeMetadata ()

语法	比特数	助记符
getObjectsTypeMetadata () {		
position;		
widthOut;	2	uimsbf
heightOut;	2	uimsbf
depthOut;	2	uimsbf
gainOut;	2	uimsbf
if (diffuseFlag) {	1	uimsbf
Diffuse	4	uimsbf
}		
if (channelLockFlag)	1	uimsbf
channelLock	6	uimsbf
if (cartesianFlag == 0)	1	bslbf
if (objectDivergenceFlag == 1) {		
objectDivergence	4	uimsbf
azimuthRange	8	uimsbf
}		
if (zoneExclusionFlag == 1) {		

表100 (续)

语法	比特数	助记符
minAzimuth	8	uimsbf
maxAzimuth	8	uimsbf
minElevation	8	uimsbf
maxElevation	8	uimsbf
minDistance	8	uimsbf
maxDistance	8	uimsbf
}		
if (screenRef) {	1	uimsbf
screenEdgeLock	2	uimsbf
Azimuth	8	bslbf
Elevation	8	bslbf
aspectRatio	3	bslbf
screenCentrePositionAzimuth	8	bslbf
screenCentrePositionElevation	8	bslbf
screenCentrePositionDistance	8	bslbf
screenWidth_polar	8	bslbf
}		
} else {		
if (objectDivergenceFlag == 1) {		
objectDivergence	4	uimsbf
positionRange	4	uimsbf
}		
if (zoneExclusionFlag == 1) {		
minx	8	uimsbf
maxX	8	uimsbf
minY	8	uimsbf
maxY	8	uimsbf
minZ	8	uimsbf
maxZ	8	uimsbf
}		
if (screenRef) {	1	uimsbf
screenEdgeLock;	2	uimsbf
Azimuth	8	bslbf
Elevation	8	bslbf
aspectRatio	3	bslbf
screenCentrePositionX	8	bslbf
screenCentrePositionY	8	bslbf

表100 （续）

语法	比特数	助记符
screenCentrePositionZ	8	bslbf
screenWidth_cartesian	8	bslbf
}		
}		
}		

基于对象渲染的语法见表101。

表101 基于对象渲染的语法objectsRender（）

语法	比特数	助记符
objectsRender（）{		
getTypeMetadata（）；		
setLayout（）；		
objectGainCalculate（）；		
while（!eof）{		
audioProcess（）；		
}		
}		

基于对象的增益计算的语法见表102。

表102 基于对象的增益计算的语法objectGainCalculate（）

语法	比特数	助记符
objectGainCalculate（）{		
decorrelate（）；		
directGain ；	2	uimsbf
diffuseGain ；	2	uimsbf
setLayout（ bs2051Layouts ）；	4	bslbf
panner（）；		
}		

屏幕边缘锁定的语法见表103。

表103 屏幕边缘锁定的语法screenEdgeLock（）

语法	比特数	助记符
screenEdgeLock（）{		
getOutPosition（）；		
}		

10.5 基于对象的渲染语义

基于对象的渲染语义见表104。

表104 基于对象的渲染语义

名称	语义
position	audioBlockFormat 中基于对象音频的位置
screenEdgeLock	见表 103
directGain	直达声 gain
diffuseGain	发散声 gain
decorrelate ()	根据发散声计算发散延迟，去相关后的增益（获取输入增益后，通过 FFT 转换为频域值，设置随机种子参数，获得不同的 FIR 滤波器，获取发散频率值，频域转换为时域后得到发散延迟、增益）
audioProcess ()	根据 calculate () 计算得到的增益对音频信号进行处理，得到渲染后的音频信号
panner ()	配置各个扬声器输出信号增益（基于 VBAP 的增益计算，在给定扬声器布局和方向的设置后，它为每个扬声器产生一个增益，使监听者获得自己创作意图方向）
getLayout ()	获得依据 ITU-RBS.2051 建议名称定义的扬声器布局（如:0+2+0）
getOutPosition ()	获得重放音频输出位置
bs2051Layouts	BS2051 扬声器布局配置，4 比特。 0x0: 0+2+0, 0x1: 0+5+0, 0x2: 2+5+0, 0x3: 4+5+0, 0x4: 4+5+1, 0x5: 3+7+0, 0x6: 4+9+0, 0x7: 9+10+3, 0x8: 0+7+0
widthOut	导出宽元数据参数
heightOut	导出高元数据参数
depthOut	导出深元数据参数
gainOut	导出增益参数
cartesianFlag	判断是否为元数据坐标
diffuseFlag	判断是否发散
channelLockFlag	判断是否锁定通道
objectDivergenceFlag	判断是否分离散射
zoneExclusionFlag	判断是否排除区域

10.6 基于声道的渲染语法

基于声道的渲染语法同样涉及 metadata 元数据类型、directspeakersRender 声道渲染器、directGainCalculate 增益计算等类和库。

获取基于声道元数据的语法见表 105。

表105 获取基于声道元数据的语法getDirectSpeakersTypeMetadata元数据类型

语法	比特数	助记符
getDirectSpeakersTypeMetadata () {		
audioPackFormatID	11 × 8	bslbf
speakerLabel	4	bslbf
lowPassFlag	1	uimsbf
highPassFlag	1	uimsbf
if (cartesianFlag == 0) {		
azimuth	8	uimsbf
azimuthMin	8	uimsbf
azimuthMax	8	uimsbf
elevation	8	uimsbf
distance	8	uimsbf
} else {		
X	8	uimsbf
Y	8	uimsbf
Z	8	uimsbf
}		
if (screenRef) {		
screenEdgeLock;	2	uimsbf
}		
}		

基于声道渲染的语法见表106。

表106 基于声道渲染的语法directspeakersRender ()

语法	比特数	助记符
directspeakersRender () {		
{		
getDirectSpeakersTypeMetadata () ;		
getLayout () ;		
directGainCalculate () ;		
While (!eof) {		
audioProcess () ;		
}		
}		

基于声道的增益计算的语法见表107。

表107 基于声道的增益计算的语法directGainCalculate ()

语法	比特数	助记符
directGainCalculate () {		
directGain;	4	bslbf
getLayout (bs2051Layouts) ;	4	bslbf
panner () ;		
}		

10.7 基于声道的渲染语义

基于声道的渲染语义见表108。

表108 基于声道的渲染语义

名称	语义
PolarSpeakerPosition ()	扬声器位置参数（球极坐标）
CartesianSpeakerPosition ()	扬声器位置参数（元数据坐标）
getDirectSpeakersTypeMetadata ()	获得扬声器的元数据信息
directGainCalculate ()	基于声道的增益计算
lowPassFlag	标识音频信号是否 lfe
highPassFlag	标识音频信号是否中高频
audioPackFormatID	见表 13
speakerLabel	扬声器的标识，参考 BS.2051
screenEdgeLock	见表 103
directGain	各个位置的增益

10.8 基于 HOA 的渲染语法

获取基于HOA元数据的语法见表109。

表109 获取基于HOA元数据的语法getHOATypeMetadata ()

语法	比特数	助记符
getHOATypeMetadata () {		
order;	3	uimsbf
degree;	4	uimsbf
normalization;	2	uimsbf
nfcRefDist;	6	uimsbf
if (screenRef) {	1	bslbf
screenEdgeLock;	2	uimsbf
}		
defaultScreenSize;		
}		

基于HOA渲染的语法见表110。

表110 基于HOA渲染的语法hoaRender ()

语法	比特数	助记符
hoaRender () {		
{		
getHOATypeMetadata ()		
getLayout () ;		
hoaGainCalculate () ;		
While (!eof) {		
audioProcess () ;		
}		
}		

基于 HOA 增益计算的语法见表 111。

表111 基于HOA增益计算的语法hoaGainCalculate ()

语法	比特数	助记符
hoaGainCalculate () {		
normalizeDecodeMatrix () ;		
allradDesign () ;		
directGain;	4	bslbf
panner () ;		
}		

全方向解码音频处理的语法见表112。

表112 全方向解码音频处理的语法allradDesign ()

语法	比特数	助记符
allradDesign ()		
{		
calcY () ;		
calcG () ;		
getHoaDecodeMatrix () ;		
}		

获得HOA虚拟扬声器位置矩阵语法见表113。

表113 获得HOA虚拟扬声器位置矩阵的语法calcY ()

语法	比特数	助记符
calcY ()		
{		
hoaOrders[(order+1) ²]		
hoaDegrees[(order+1) ²]		
for (j = 0; j < sourcePointsNum; j++) {		
for (i = 0; i < (order+1) ² ; i++) {		
hoaAzimuth = -atan2 (sourcePoints[j][0], sourcePoints[j][1]) ;		
hoaElevation = atan2 (sourcePoints[j][2],		
hypot (sourcePoints[j][0], sourcePoints[j][1])) ;		
Y_virt[i][j]=sphHarm (hoaOrders[i], hoaDegrees[i], hoaAzimuth,		
hoaElevation, normalization) ;		
}		
}		
}		

归一化球面坐标谐波计算的语法见表114。

表114 归一化球面坐标谐波计算的语法sphHarm ()

语法	比特数	助记符
sphHarm (order, degree, azimuth, elevation, normalization) {		
if (degree > 0)		
scale = sqrt (2.0) × cos (degree × azimuth) ;		
else if (degree < 0)		
scale = sqrt (2.0) × sin (degree × azimuth) ;		
res = normalization (order, abs (degree)) × Alegendre (order, abs (degree),		
sin (elevation)) × scale;		
}		

获得输出扬声器的定位矩阵的语法见表115。

表115 获得输出扬声器的定位矩阵的语法calcG ()

语法	比特数	助记符
calcG ()		
{		
speakerNum = size (panningFunction ([0, 1, 0], normalization, layout)) ;		
for (i = 0; i < sourcePointsNum; i++) {		
G_virt[i][speakerNum]=panningFunction (sourcePoints[i],		
normlization, layout) ;		
}		
}		

获得输出扬声器的HOA解码矩阵的语法见表116。

表116 获得输出扬声器的HOA解码矩阵的语法getHoaDecodeMatrix ()

语法	比特数	助记符
getHoaDecodeMatrix ()		
{		
hoaDecodeMatrix[(order+1) ²][speakerNum] = transpose (Y_virt) ×G_virt;		
}		

10.9 基于 HOA 的渲染语义

基于HOA的渲染语义见表117。

表117 基于HOA的渲染语义

名称	语义
hoaOrders	获得对应HOA阶数的虚拟扬声器通道数
hoaDegrees	获得对应HOA阶数的虚拟扬声器度数
hoaAzimuth	获得HOA虚拟扬声器方位角
hoaElevation	获得HOA虚拟扬声器仰角
Y_virt	获得HOA系数矩阵，维度为：球谐分布值与对应归一化阶数的虚拟扬声器通道数值
sourcePoints	从基于HOA音频读取的分布于球面的虚拟扬声器声源点坐标
sourcePointsNum	虚拟扬声器声源点的数量
sphHarm ()	对声源位设置归一化的球谐值，参数输入见表104
speakerNum	输出扬声器通道数量
G_virt	输出扬声器的增益矩阵G_virt，维度为：球谐分布值与对应输出扬声器布局的通道数值
panningFunction ()	依据输出扬声器布局配置从三个向量值归一化为一个用于Pan的向量
hoaDecodeMatrix	HOA解码器矩阵
directGain	各个HOA声道的直达声gain

附录 A

(资料性)

HRTF 库的模式选择

A.1 简介

虚拟现实音频技术在进行双耳渲染时会用到 HRTF, HRTF 可将无方位感的单声道音频信号经滤波得到左右两路音频信号, 这个双声道立体声信号将体现声音的方位感。

A.2 可供参考的HRTF

目前, 国际上公开的 HRTF 数据库主要采用 AES 协会在 AES69-2020 标准中规定的 SOFA 格式进行存储, 下面的链接中提供了相应的下载信息和相应读取方式, 其中数据库包括实际人头测量、假人头测量、含房间混响等的 HRTF 数据库:

[https://www.sofaconventions.org/mediawiki/index.php/SOFA_\(Spatially_Oriented_Format_for_Acoustics\)](https://www.sofaconventions.org/mediawiki/index.php/SOFA_(Spatially_Oriented_Format_for_Acoustics))

下方链接为 22.2 声道测量的双耳房间脉冲响应的下载信息:

https://github.com/IoSR-Surrey/IoSR_ListeningRoom_BRIRs

注: SOFA 只是一种文件格式, 使用该形式提供的 HRTF 数据库时需审阅对应 HRTF 库的 license 文件, 如网站上的 HUTUBS 数据库采取 Attribution 4.0 International (CC BY 4.0), chedar 数据库采取 Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0), 使用时需自行评估 license 相关条款。

22.2 声道测量的双耳房间脉冲响应 license 为 Attribution 4.0 International (CC BY 4.0)。由于链接涵盖了这些信息, 附录 A 无需重复陈述。

A.3 HRTF 使用方案

一般在 HRTF 数据库储存 HRIR 数据, 即 HRTF 的时域表达形式, 可视作脉冲响应。使用时可根据需要读取对应角度的 HRIR 数据, 与输入的 PCM 码流做卷积。

根据计算能力和延时方面出发考虑, 应结合具体使用场景以及具体 HRIR 来调整使用方案, 如采用对 HRIR 拖尾做一定的截断, 不使用 HRIR 前端的废数据等方法。

A.4 HRTF和附录C中采样卷积混响的使用方案

由于 HRTF 的时域形式 HRIR 和采样卷积混响 IR 在本质上都是脉冲响应, 所以使用上可以采用两种方案:

1. 将 HRTF 的时域模式 HRIR 和采样卷积混响 IR 先做卷积得到一个更长的 FIR 滤波器, 然后用此滤波器跟输入信号做快速卷积, 先集成的好处是可以凑够较长的序列然后便于做快速卷积。

2. HRTF 和采样卷积混响分开, 即先经过 HRTF 处理再送入采样卷积混响。这样分步骤比较适合运动场景以及多路声音的处理。比如多路声音先经各自不同的 HRTF 处理, 然后混音, 再送入采样卷积混响, 而不是各自都经过较长的, HRIR 卷积上采样卷积混响 IR 后的序列, 再混音。

以上两种方案都是从计算量，延时方面出发考虑，应结合具体使用场景以及具体 HRIR 和采样卷积混响 IR 的长度来调整使用方案。

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附 录 B
(资料性)

一种基于头相关传输函数线性插值的 VR 音频方法

B.1 概述

附录 B 提供了一种头相关传输函数（HRTF）的线性插值方法，用来预测空间未知位置的 HRTF，提高 HRTF 数据的空间分辨率。通过对待输入的单路音频进行空间定位渲染，最终通过耳机回放具有空间方位感的音频。

B.2 技术框架

附录 B 采用基于最小相位估计与计算双耳时间差（ITD）的 HRTF 幅值线性插值方法，预测得到了分辨率更高的可以用来进行音频实时渲染的 HRTF 数据库（360 个方向，间隔 1 度），考虑到应用场景里需要实现任意方向音频的实时渲染，因此需要算法复杂度和时间复杂度都比较低，插值渲染算法的技术框架如图 B.1 所示。

1) 首先提取 HRTF 的幅值信息，通过线性插值的方法得到未知位置的 HRTF 幅值大小。然后利用 HRTF 幅值与最小相位的希尔伯特变换关系得到最小相位信息，补全未知位置的 HRTF，最后反傅里叶变换得到 HRIR，存储所有空间方向的 HRIR 组成一个数据库。

2) 以上得到的最小相位信息不能直接反映原始相位中的双耳时间差（ITD），因此附录 B 采用左右耳互相关的方法计算得到 ITD，并在立体声还原过程中补充预测得到的左右耳延时大小，形成完整的延时定位信息。

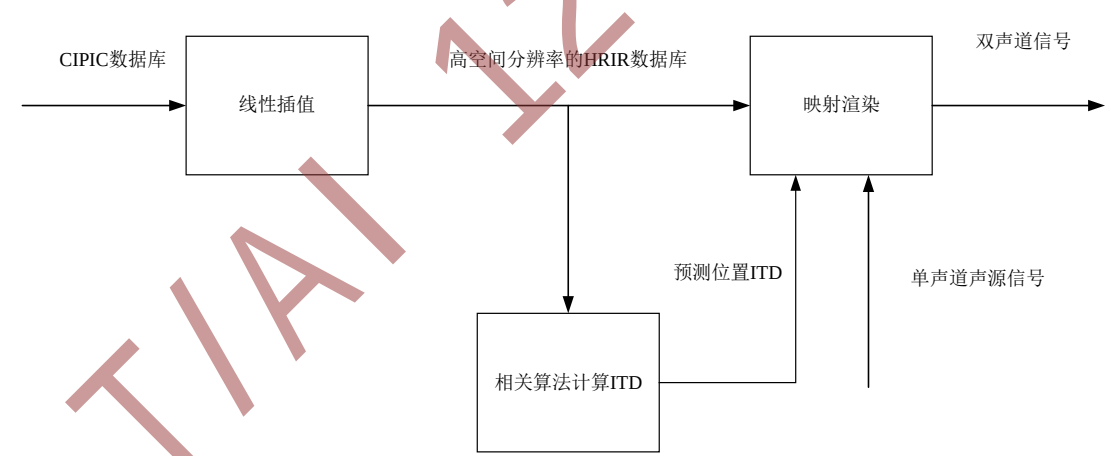


图 B.1 基于 HRTF 线性插值的三维音频定位渲染技术框架

B.3 基于幅值线性插值与最小相位估计的HRTF预测原理

首先通过公式（B.1）能够得到相邻间隔 1 度的任意水平方位角的 HRTF 幅值大小，但是要得到完整的 HRIR 需要补充相位信息。相位中包含有对应时域 HRIR 的双耳时延，幅值里面包含的 ILD 与相位中体现的 ITD 信息是人耳声源定位中关键的两部分。

$$\hat{H}(\theta, \varphi, f) \approx \frac{\theta_{i+1} - \theta}{\theta_{i+1} - \theta_i} H(\theta_i, \varphi, f) + \frac{\theta - \theta_i}{\theta_{i+1} - \theta_i} H(\theta_{i+1}, \varphi, f) \quad \dots\dots (B.1)$$

式中：

θ ——水平角；

φ ——高度角；

F ——频率；

θ_{i+1} ——相邻水平角。

按照信号处理理论，作为线性时不变系统的传输函数，HRTF 又可以分解为最小相位函数、全通相位函数和线性相位函数的乘积，如公式（B.2）所示：

$$H(\theta, \phi, f) = H_{\min}(\theta, \phi, f) \exp[j\psi_{\text{all}}(\theta, \phi, f)] \exp[-j2\pi f T(\theta, \phi)] \dots\dots (B.2)$$

式中：

$H_{\min}(\theta, \phi, f)$ ——最小相位函数；

$\psi_{\text{all}}(\theta, \phi, f)$ ——全通相位函数；

$T(\theta, \phi)$ ——线性相位函数。

其次，HRTF 的最小相位重构是按照最小相位函数的相位信息进行相位重构，它是原始相位的一种近似。并且这个最小相位信息与幅值遵循希尔伯特变换关系，如公式（B.3）所示：

$$T_{\min} = -\text{Hilbert}[\log(\text{abs}(H_{\min}))] \dots\dots (B.3)$$

式中：

Hilbert ——希尔伯特变换。

最后，可以将 HRTF 近似为一个最小相位函数和线性相位函数（纯延时+总延时）的乘积，忽略了全通相位函数。公式如式（B.4）所示：

$$H(\theta, \phi, f) \approx H_{\min}(\theta, \phi, f) \exp[-j2\pi f T(\theta, \phi)] \dots\dots (B.4)$$

依照以上理论基础，附录 B 中的 HRTF 相位信息补偿过程分为以下三步：1) 最小相位重构，即利用最小相位函数的相位信息重构未知位置的 HRTF 函数；2) 计算 ITD，即双耳时间差；3) 计算总延时，即头中心到声源距离的时延。

B.4 双线性插值方法

双线性插值是上面的相邻线性插值方法在三维空间的推广。假设 HRTF 的测量是在等声源距离的情况下进行的，声源位置分布在一个 $r = r_0$ 的球面上。如果分别沿 θ 和 φ 对空间方向进行采样，则已测量声源位置之间的连线构成球面上的网格，网格的顶点表示已测量的空间位置。其示意图如图 B.2：

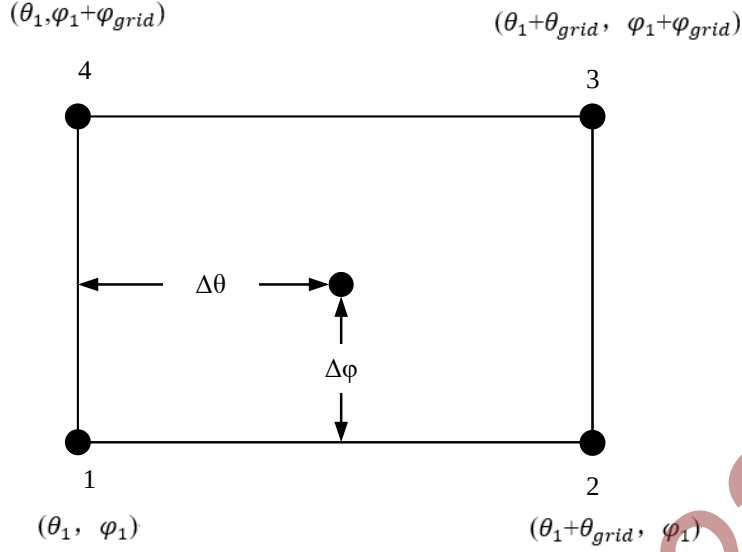


图 B.2 空间双线性插值示意图

假设沿 θ 方向的采样间隔为 θ_{grid} ， φ 方向的采样间隔为 φ_{grid} 。已测量得到编号为 1、2、3、4 四个相邻顶点的 HRTF，记为：

$$\begin{aligned} H(1, f) &= H(\theta_1, \varphi_1, f) & H(2, f) &= H(\theta_1 + \theta_{\text{grid}}, \varphi_1, f) & \dots\dots (B.5) \\ H(3, f) &= H(\theta_1 + \theta_{\text{grid}}, \varphi_1 + \varphi_{\text{grid}}, f) & H(4, f) &= H(\theta_1, \varphi_1 + \varphi_{\text{grid}}, f) \end{aligned}$$

利用多元函数的泰勒级数展开，网格内 $(\theta, \varphi) = (\theta_1 + \Delta\theta, \varphi_1 + \Delta\varphi)$ 方向的 HRTF 可近似为 1、2、3、4 四个相邻点的 HRTF 的线性组合或者权重平均：

$$\hat{H}(\theta, \varphi, f) \approx A_1 H(1, f) + A_2 H(2, f) + A_3 H(3, f) + A_4 H(4, f) \dots\dots (B.6)$$

其中，

$$A_1 = (1 - A_\theta)(1 - A_\varphi) \quad A_2 = A_\theta(1 - A_\varphi) \quad A_3 = A_\theta A_\varphi \quad A_4 = (1 - A_\theta)A_\varphi \dots\dots (B.7)$$

$$A_\theta = \frac{\Delta\theta}{\theta_{\text{grid}}} \quad A_\varphi = \frac{\Delta\varphi}{\varphi_{\text{grid}}} \dots\dots (B.8)$$

三点相邻线性插值的伪代码描述如下：

```
BilinearInterp (array, length_0, length_1)
    original_0 = array.GetLength (0)
    original_1 = array.GetLength (1)
    ReScale_0 = original_0 / length_0
    ReScale_1 = original_1 / length_1
    for (i = 0; i < length_0; i++)
        for (int j = 0; j < length_1; j++)
            index_0 = i × ReScale_0
            index_1 = j × ReScale_1
            inde_0 = FloorToInt (index_0)
```

```

inde_1 = FloorToInt (index_1)
s_leftUp = (index_0 - inde_0) × (index_1 - inde_1)
s_rightUp = (inde_0 + 1 - index_0) × (index_1 - inde_1)
s_rightDown = (inde_0 + 1 - index_0) × (inde_1 + 1 - index_1)
s_leftDown = (index_0 - inde_0) × (inde_1 + 1 - index_1)
out[i, j] = array[inde_0, inde_1] × s_rightDown + array[inde_0 + 1, inde_1]
× s_leftDown + array[inde_0 + 1, inde_1 + 1] × s_leftUp + array[inde_0,
inde_1 + 1] × s_rightUp

return out

```

其中, array 为待测点附近的原始 HRTF 数据矩阵; length_0、length_1 分别为待预测位置的 $\Delta\theta$ 和 $\Delta\varphi$; array.GetLength () 函数用于获得 array 中的 θ_{grid} 和 φ_{grid} ; FloorToInt () 函数用于向下取整; out[]为输出的预测 HRTF 值。

B.5 双耳时间差 (ITD) 的计算补偿方法

首先由 HRTF 可以计算出双耳时间差 ITD, 且在频率小于 1.5kHz 的低频信号中, 双耳声压相延时差是声源方向定位的一个重要因素。可利用 HRTF 分析不同声源产生的双耳声压相延时差和包络时差。

附录 B 是采用相对稳定的归一化互相关函数的方法来预测对应位置的 ITD。关于离散时间 HRIR 的归一化互相关函数表示如式 (B.9) 所示:

$$\Phi_{LR}(k) = \frac{\sum_{n=1}^N h_L(n+k)h_R(n)}{\{[\sum_{n=1}^N h_L^2(n)] \times [\sum_{n=1}^N h_R^2(n)]\}^{1/2}} \quad \dots\dots (B.9)$$

式中:

n ——原始 HRIR 的离散时间信息;

k ——延时的样本点数。

上式定义, $0 \leq |\Phi_{LR}(k)| \leq 1$ 。由上式可以计算出函数 $\Phi_{LR}(k)$ 在 $|T| \leq 1\text{ms}$, 即 $-44 \leq k \leq 44$ 范围内的最大值, 而与此相应的 $k = k_{\text{max}}$ 即为相关法定义的双耳时间差 ITD_{corre} 即:

$$ITD_{\text{corre}}(\theta, \varphi) = k_{\text{max}} \quad \dots\dots (B.10)$$

附录B基于相关法, 对各空间位置的HRIR求双耳的互相关函数得到ITD, 然后将预测得到的ITD信息根据采样率转换为时域的延时信息, 对左右耳声道渲染输出的信号前面进行补零, 最终输出带有空间方位感知的双声道音频。

附录 C
(资料性)
人工混响模式

C.1 人工混响

C.1.1 混响器模型

人工混响采用 Moorer 混响器模型，音频信号通过并联的多个低通梳状滤波器和几个串联的全通滤波器，再加上一个 N 阶 FIR 延迟滤波器生成早期反射声，最后通过一个延时模块，实现悦耳自然的混响效果。人工混响 Moorer 模型如图 C.1:

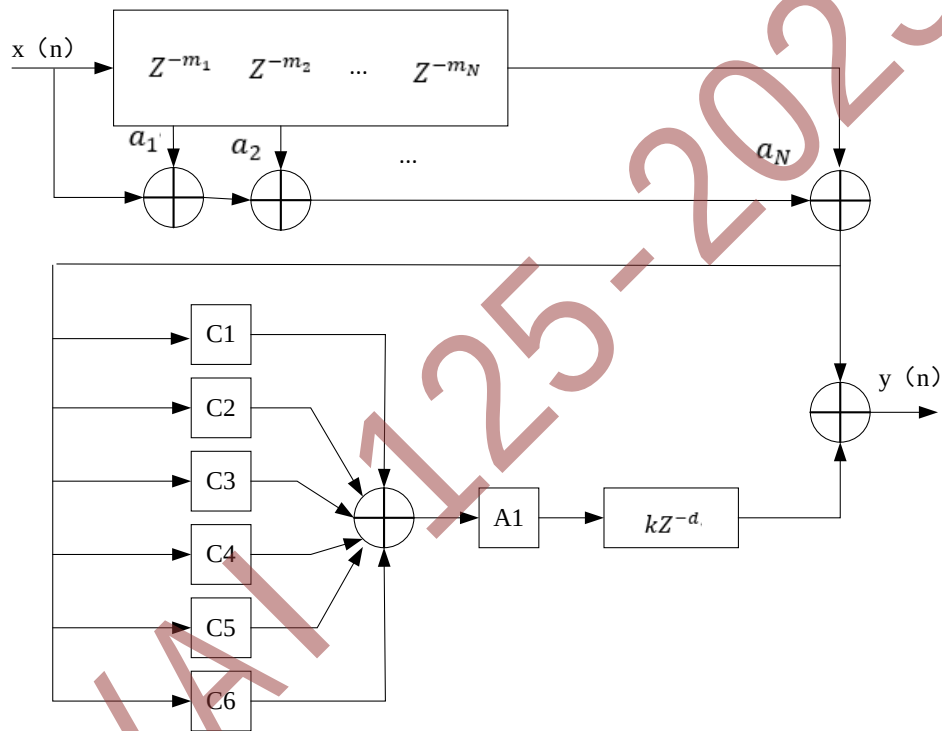


图 C.1 人工混响 Moorer 模型示意图

C.1.2 混响器语法

混响器语法见表C.1。

表C.1 混响器Moorer_Reverb () 语法

语法	比特数	助记符
Moorer_Reverb ()		
{		
sampling_frequency_index	4	uimsbf
ntaps	6	uimsbf
ncombs	6	uimsbf

表 C.1 （续）

语法	比特数	助记符
lpf_cutoff_freq	8	uimsbf
nap	2	uimsbf
reserved	2	bslbf
reflection_coeff	4	uimsbf
Td	8	uimsbf
mix	7	uimsbf
reserved	1	bslbf
tapminms	8	uimsbf
tapmaxms	8	uimsbf
rm_length	8	uimsbf
rm_width	8	uimsbf
rm_height	8	uimsbf
npaths	3	uimsbf
reserved	5	bslbf
}		

C. 1. 3 混响器参数

sampling_frequency_index	见GB/T 33475.3附录 A.2节
ntaps	6比特，FIR滤波器的阶数，范围为1到64阶
ncombs	6比特，梳状滤波器的个数，范围为1到64个
nap	2比特，全通滤波器的个数，范围为1到4个
lpf_cutoff_freq	8比特，低通滤波器的截止频率，见表C.2
reflection_coeff	4比特，墙体材料反射系数，见表C.3
Td	8比特，混响时间，范围为0.0s到20.0s，1比特对应0.078125s
mix	7比特，音频信号干湿比（%），范围为0%到100%，见表C.4
tapminms	8比特，FIR最短延迟时间，范围为1ms到256ms。
tapmaxms	8比特，FIR最长延迟时间，范围为1ms到256ms。 实际中tapminms小于tapmaxms，若tapminms大于tapmaxms，则tapmaxms等于tapminms。
rm_width	8比特，房间的宽,范围为0.0米到25.5米,1比特对应0.1米
rm_height	8比特，房间的高,范围为0.0米到25.5米,1比特对应0.1米
rm_length	8比特，房间的长,范围为0.0米到25.5米,1比特对应0.1米
npaths	3比特，反射声路径条数，范围为1到6，见表C.5

表C. 2 低通滤波器截止频率映射表

lpf_cutoff_freq	截止频率（Hz）
0x00	20
0x01	21

表 C. 2（续）

lpf_cutoff_freq	截止频率（Hz）
0x02	22
.....	
0xC7	200
0xC8	300
0xC9	400
.....	
0xD9	2000
0xDA	3000
0xDB	4000
.....	
0xEB	20000
0xEC~0xFF	保留

表C. 3 墙体材料反射系数映射表

reflection_coeff	值
0x0	0.0
0x1	0.1
0x2	0.2
.....	
0xa	1.0
0xb~0xf	保留

表C. 4 音频信号干湿比映射表

mix	百分比 （%）
0x0	0
0x1	1
0x2	2
.....	
0x64	100
0x65~0x80	保留

表C. 5 反射声路径条数映射表

npaths	条
0x0	0

表C.5 （续）

npaths	条
0x1	1
0x2	2
.....	
0x6	6
0x7~0x8	保留

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附录 D

(资料性)

一种基于 Ambisonics 全景录音球的麦克风阵列摆放实施方案

D.1 概述

Ambisonics 是一种应用于声场感知和声场重建的技术，运用球谐函数理论，以实现声场的分析和重构。球面分布的麦克风阵列可以用于 Ambisonics 录音，记录声场信息。附录 D 主要研究了对任意数量的满足 Ambisonics 录音要求的麦克风阵列的均匀摆放问题，并给出了一种具有普适性的解决方案。

D.2 技术框架

D.2.1 整体方案

在用于 Ambisonics 录音的采样球中，麦克风的位置需满足球谐函数的离散正交性，以使对声场 HOA 系数求解更加准确和全面；而一般情况下，只有五种正多面体的顶点满足此条件。为使任意数量的麦克风均满足正交性，尽可能均匀地分布于球面上，附录 D 引入一种物理模型，采用静电场的平衡条件来模拟这一分布问题，将采样球表面视为导体球表面，将麦克风视为带电粒子，并假设各带电粒子之前存在类似库仑力的平方反比力。当带电粒子的运动达到平衡时，可视为在球面上均匀分布。运用这一方法，可以确定各麦克风在球面上的位置。

D.2.2 具体实现方法

采用上述物理模型实现麦克风阵列均匀分布的具体步骤如下：

- 1) 对球形 3D 录音系统进行建模，得到一单位球体；然后将待分布的 N 个麦克风作为带电粒子，随机分布在该单位球体的表面；
- 2) 计算每个带电粒子在各个方向上受到的合力大小，然后计算出合力在对应带电粒子上的切线分量；
- 3) 根据切线矢量计算对应带电粒子沿切向运动飞出该单位球体表面的坐标，然后对每一带电粒子的坐标沿径向进行归一化，使所有带电粒子再次回到该单位球体的表面；
- 4) 步骤 ii、iii 循环若干次，当各带电粒子所受合力均小于一设定值时，得到各带电粒子的球面均匀分布，即为 N 个麦克风在该球形 3D 录音系统的阵列分布。

其流程图如图 D.1 所示。

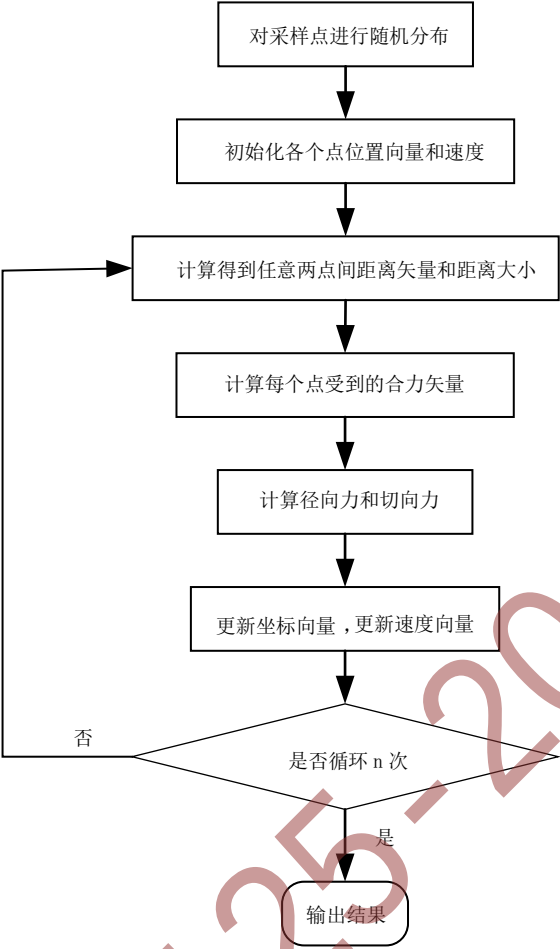


图 D.1 实现方法流程图

D.3 实现方法效果评测

为验证附录 D 摆放方法的合理性，需要观察用此方法得到的麦克风阵列的正交性。这一特性可以通过计算正交误差矩阵得到：

$$D = I_K - \frac{1}{Q} Y^T Y \quad \dots\dots (D.1)$$

式中：

- I_K —— $K \times K$ 的单位矩阵；
- K ——球谐函数组包含球谐函数的个数；
- Q ——麦克风（采样点）的个数；
- Y ——离散的球谐函数组构成的矩阵；
- D ——了该摆放方案与理想正交情况（单位矩阵I）的误差。

首先，以 32 个麦克风得到的结果为例，计算得到的误差矩阵如图 D.2:

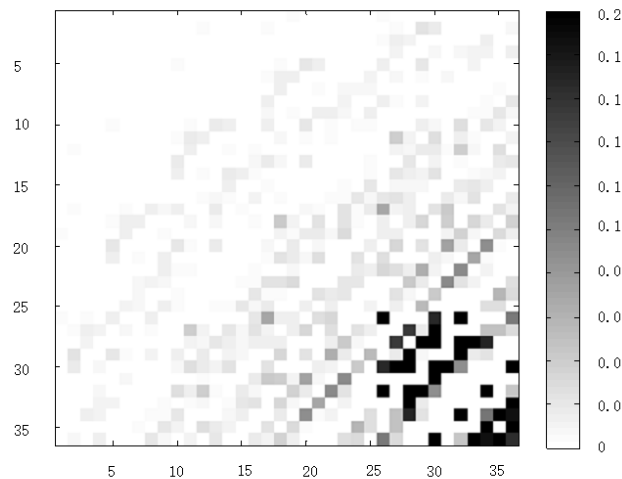


图 D. 2 正交误差矩阵

由此可见，在 1 阶至 4 阶 Ambisonics（对应矩阵 1 至 25 列）范围内，该方法得到的麦克风摆放已经具有很高的正交性，可以很精确地采集到声场信息；当阶数超过 5 阶时误差有所增大，但是已经超出一般测量范围，故并不影响实际测量时的精确度。

当麦克风数量变化时，正交性的误差也会有所变化。固定 Ambisonics 最高阶数为 4 阶，麦克风数量变化范围为 25 到 35，令 d_n 为正交误差矩阵D中每一个元素的误差总和，绘制不同麦克风数量下的 d_n 如图 D.3：

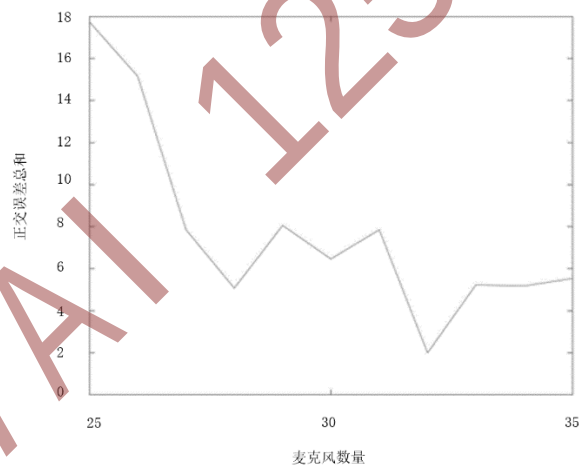


图 D. 3 不同麦克风数量下的正交性误差之和

由图 D.3 可知，在 4 阶 Ambisonics 条件下，当麦克风数量为 32 时，其正交误差最小。最后，附录D与一种已有的针对 32 麦克风的球面阵列摆放方法(Pentakis-dodecahedron)进行了比较以验证其效果。图 D.4，图 D.5 给出了两种方案在 4 阶 Ambisonics 下的正交误差矩阵：

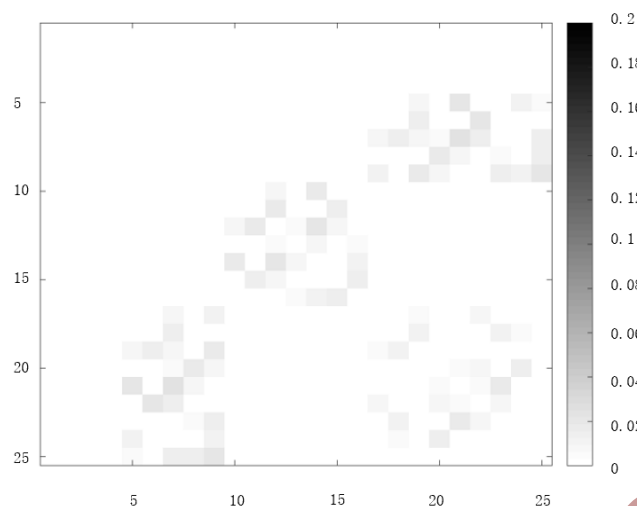


图 D.4 附录所述摆放方法的四阶正交误差矩阵

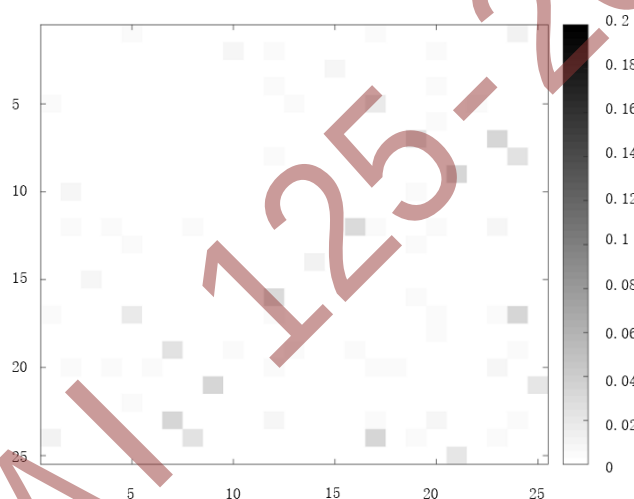


图 D.5 Pentakis-dodecahedron 摆放方法的四阶正交误差矩阵

由对比可见，在 32 麦克风数量时，附录 D 所述摆放方法，其正交性与已有的方法效果相似。

D.4 结论

由于 Ambisonics 系统对麦克风阵列正交性的限制，而理想情况下只有五种正多面体的顶点分布满足这种要求，这就大大限制了采样球的设计和范围。附录 D 采用物理模拟的方法，通过模拟带电粒子在导体球面的受力平衡确定出任意数量麦克风在球面近似均匀的分布，同时也满足较好的正交性。这一结果提高了可供编解码的 Ambisonics 阶数，具有实用性意义，另外，与已有的针对固定数量麦克风摆放方案相比，附录 D 所述方法在麦克风数目设置上完全任意，提高了实际操作灵活性。

D.5 32 采样点的球面麦克风阵列摆放

如图 D.6 所示：

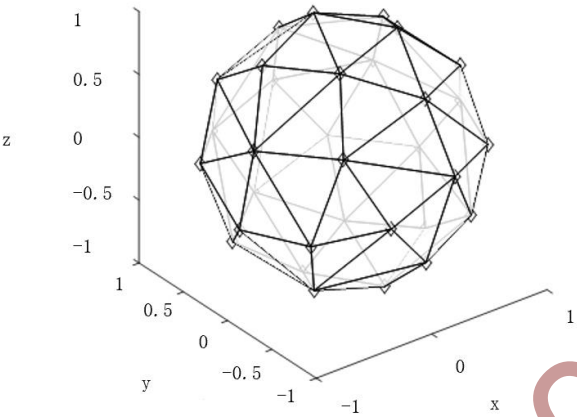


图 D. 6 球面麦克风阵列摆放位置

其中每个点的位置坐标（以元数据坐标显示）：

表 D. 1 球面麦克风阵列摆放位置坐标

序号	x	y	z
1	0.549692	0.58148	0.599766
2	-0.54969	-0.58148	-0.59977
3	-0.34848	0.143062	0.926334
4	0.853771	0.023012	0.52014
5	-0.99281	0.067463	0.09887
6	-0.13259	-0.45845	0.878772
7	-0.75578	-0.23755	0.610216
8	-0.71721	0.468747	0.515648
9	-0.77777	0.601339	-0.18295
10	0.755782	0.237551	-0.61022
11	0.269155	0.950211	0.157016
12	0.070173	-0.68436	-0.72576
13	0.717206	-0.46875	-0.51565
14	-0.46046	-0.77684	0.429528
15	-0.07017	0.684361	0.725758
16	-0.3685	0.90695	0.204082
17	-0.49286	0.459158	-0.7391
18	-0.26916	-0.95021	-0.15702
19	-0.16816	0.898901	-0.4046
20	0.168162	-0.8989	0.404597
21	0.348481	-0.14306	-0.92633

表 D.1 (续)

序号	x	y	z
22	0.13259	0.458453	-0.87877
23	-0.85377	-0.02301	-0.52014
24	-0.29114	-0.11132	-0.95018
25	0.492855	-0.45916	0.739099
26	0.992811	-0.06746	-0.09887
27	0.777766	-0.60134	0.182951
28	0.460464	0.776839	-0.42953
29	-0.84018	-0.54147	-0.02994
30	0.840184	0.541475	0.029937
31	0.291139	0.111321	0.950182
32	0.3685	-0.90695	-0.20408

D.6 实现流程的详细描述和伪代码描述

首先运用随机数函数，对采样点的坐标进行赋值，得到各采样点的三维坐标向量为 r_0 。

设定各个点的初始速度向量 $v_0=[0,0,0]$ 。

设定斥力常数为 G ，代表加速度和力之间的正比关系。

设定循环次数初值为 1， $n=1$ 。

把位置坐标向量 r_0 和速度向量 v_0 带入到循环中，通过不断重复下面过程对位置坐标和速度进行更新：

将球面任意两个点 i, j 的三维坐标相减，计算每两个点之间的距离矢量 dd_{ij} ，

$$dd_{ij} = r_i - r_j \quad \dots\dots (D.2)$$

将任意两点的距离矢量 dd_{ij} 进行取模，计算出两点间距离大小 L_{ij} ，为了避免距离过小，限定最小距离 L_{min} ，当距离 L 小于 L_{min} 时，令 L 等于 L_{min} 。

$$L_{ij} = |dd_{ij}|; L (L < L_{min}) = L_{min} \quad \dots\dots (D.3)$$

我们假定任意两点之间的斥力与距离的平方呈反比，则点 i 受到点 j 的斥力可以用两点之间距离矢量 dd_{ij} 除以距离大小 L_{ij} 的三次方来计算，之后对受到的其他点的斥力进行加和，得到 i 点所受到的各个点的合力，将合力存储在向量 F_i 中；

$$F_i = \sum_{j \neq i} dd_{ij} / (L_{ij})^3 \quad \dots\dots (D.4)$$

对于每一个点 i ，将所受合力 F_i 与粒子坐标 r_i 做内积，将结果再与坐标 r_i 进行点乘，得到点 i 所受到合力的径向分量 Fr_i ，这个分量不会对运动产生影响；

$$Fr_i = r_i * (F_i \cdot r_i) \quad \dots\dots (D.5)$$

把合力 F_i 减去径向分量 F_{r_i} ，得到合力的切向分量 F_{v_i} ，在切向分量的作用下，粒子会在径向的方向产生一个加速度。切向分量计算如下：

$$F_{v_i} = F_i - F_{r_i} \quad \dots\dots (D.6)$$

加速度大小与力成正比，利用加速度对速度进行更新，依据合力的切向分量和斥力常数 G 乘积，得到当前的速度向量 v_i^n 。

$$v_i^n = G * F_{v_i} \quad \dots\dots (D.7)$$

在当前速度向量 v_i^n 的作用下，点的坐标 r_i 变为原始坐标 r_i^n 与速度 v_i^n 的加和：

$$r_i = r_i^n + v_i^n \quad \dots\dots (D.8)$$

此时粒子由于沿着切向运动，新的坐标离开采样球表面，将新的坐标进行归一化，使粒子沿径向移动到新坐标对应的采样球表面的位置，得到新的坐标向量。

$$r_i^{n+1} = r_i / (|r_i|) \quad \dots\dots (D.9)$$

如果每个粒子 i 受到的合力 F_i 都小于一个设定的小值，则循环结束，否则 $n = n+1$ ，回到第一步继续进行计算。

循环结束后，可以使各个粒子的分布逐步呈现均匀分布的势态，粒子的位置实现了在球面的均匀分布，即为采样球表面麦克风均匀分布方式。

基于上述流程的伪代码实例：

```
Sub Arrange ( )
For i = 1:number of microphones Q
  set random coordinates  $r_i$  ( $|r_i| = 1$ )
  set velocity vector  $v_i = [0, 0, 0]$ 
End
While any  $F_i \geq \text{threshold}$ 
  For  $1 \leq i, j \leq Q, i \neq j$ 
     $d_{ij} = |r_i - r_j|$ 
     $L_{ij} = |d_{ij}|, L_{ij} (L_{ij} < L_{min}) = L_{min}$ 
     $F_i = \sum_{(i \neq j)} (d_{ij} / (L_{ij}^3))$ 
     $F_{r_i} = r_i \times (F_i \cdot r_i)$ 
     $F_{v_i} = F_i - F_{r_i}$ 
     $v_i = G \times F_{v_i}$ 
     $r_i = r_i + v_i$ 
     $r_i = r_i / |r_i|$ 
  End
End
End Sub
```


附 录 E
(资料性)
一种基于 Ambisonics 全景录音球的空间编码方法

E.1 概述

附录 E 基于高阶 Ambisonics 技术对球形麦克风阵列（见附录 D）实录的全景声录音信号进行空间编码（Spatial Encoding），从中提取声场的空间信息，通过 HOA 技术实现声场空间信息表达与录音设备的无关化。

Ambisonics 是一种用于记录和重现声场的技术方法，其基本思路是将空间中的声场信息进行分解，再通过多通道合成重现原声场。由于一阶 Ambisonics 记录声场的准确度欠佳，HOA 方法被提出。HOA 的实现是基于空间某一点声场的球谐函数分解。对于不同阶数的 HOA，声场展开的球谐函数级数截断到相应阶数，并用多通道来记录对应阶数与级数的球谐函数信号。基于 HOA 技术，附录 E 对球形麦克风阵列的实录信号进行空间编码，实现录音设备无关化的声场空间信息表达。

E.2 技术框架

E.2.1 基于球形麦克风阵列的全景声录音信号的空间编码方法

附录 E 以 HOA 理论为基础，对球形麦克风阵列的输出信号进行空间编码，主要工作包括对于由在球面上近似均匀分布的麦克风阵列组成的音频采集设备输出的实录信号，根据 HOA 技术原理，进行声场空间信息的提取与空间编码。编码后的信号与麦克风阵列的麦克风位置分布无关，并可根据解码方式的不同，实现在不同的设备上重放声场。

基于球形麦克风阵列的全景声录音信号的空间编码方法流程图如图 E.1 所示。

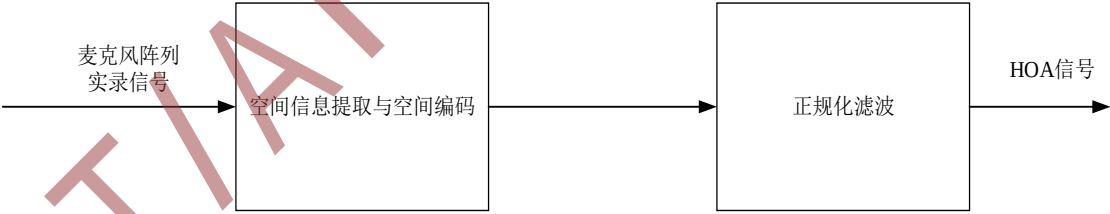


图 E.1 基于球形麦克风阵列的全景声录音信号的空间编码方法流程图

对麦克风阵列实录的信号进行空间信息的提取并进行空间编码，之后通过正规化滤波得到最终的 HOA 信号。

E.2.2 基于球谐函数分解的空间编码技术

首先，从基本的声学理论出发，考虑声波在空间内的传播。在图 E.2 所示的球极坐标系中， r 代表径向， θ 为仰角， ϕ 为水平角。

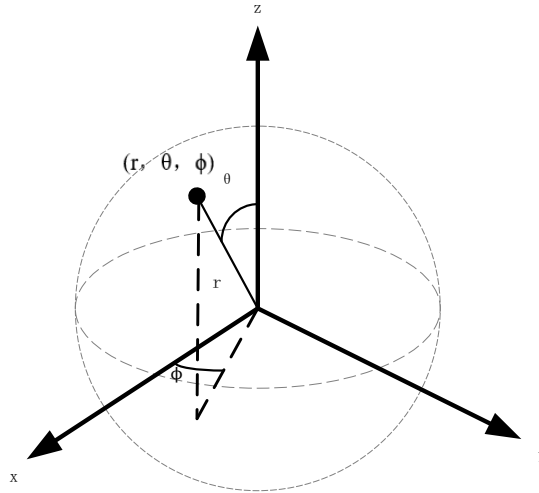


图 E.2 球极坐标系

在球极坐标系下, 对于一块不含声源的自由场空间, 其内部任意一点 (r, θ, ϕ) 的声压可以由 Fourier-Bessel 级数表示, 球极坐标系的规范如式 (E.1) 所示:

$$p(kr, \theta, \phi) = \sum_{n=0}^{\infty} i^n j_n(kr) \sum_{m=-n}^n B_n^m Y_n^m(\theta, \phi) \quad \dots\dots (E.1)$$

式中:

P ——— 声压;

j_n ——— 第一类球贝塞尔函数;

B_n^m ——— 隐含时间的系数;

$Y_n^m(\theta, \phi)$ ——— 在水平角 ϕ , 仰角 θ 方向的第 n 阶第 m 级的球谐函数。

附录 E 选取的球谐函数定义规范表示如下:

$$Y_n^m(\theta, \phi) = \sqrt{(2n+1)(2-\delta_{0,m}) \frac{(n-|m|)!}{(n+|m|)!}} P_n^{|m|}(\sin \theta) \times \begin{cases} \sin(-m\phi), & \text{if } m < 0 \\ \cos(m\phi), & \text{if } m \geq 0 \end{cases} \quad \dots\dots (E.2)$$

式中:

P_n^m ——— 连带勒让德函数。

此处采用的为实球谐函数, 而如果选用一般的复球谐函数, 也同样成立。这一球谐函数的定义规范被称为 N3D。

考虑一个简单情形, 若空间中仅有一列平面波 s , 其传播方向为 (θ_s, ϕ_s) , 振幅为 s , 波矢为 $\mathbf{k}$, 则其声压可表示为

$$p_s = s \cdot e^{j(\mathbf{k} \cdot \mathbf{r} - \omega t)} = s \cdot e^{-j\omega t} \cdot e^{ikr \cos \theta} \quad \dots\dots (E.3)$$

平面波的声压可以利用勒让德多项式展开 (平面波按球面波展开):

$$p_s = s \cdot e^{-j\omega t} \sum_{n=0}^{\infty} (2n+1) i^n j_n(kr) P_n(\cos \theta) \quad \dots\dots (E.4)$$

利用关系式

$$(2n+1)P_n(\cos\theta) = \sum_{m=-n}^n Y_n^m(\theta_s, \phi_s) Y_n^m(\theta, \phi) \quad \dots\dots (E.5)$$

其中 (θ, ϕ) 为 r 的方向, 可以将平面波声压表示为如式 (E.6) 所示形式:

$$p_s = \sum_{n=0}^{\infty} i^n j_n(kr) \sum_{m=-n}^n s \cdot Y_n^m(\theta_s, \phi_s) Y_n^m(\theta, \phi) \quad \dots\dots (E.6)$$

其中 s 已隐含了时间项。

假如已知若干列不同方向的平面波, 其在同一空间点上叠加成的声场可以用之前的级数表示, 那么对于每一列平面波, 可以定义其 HOA 信号 B_n^m

$$B_n^m = s \cdot Y_n^m(\theta_s, \phi_s) \quad \dots\dots (E.7)$$

由于平面波的任意性以及线性叠加原理, 可以利用足够多的平面波重构某一点处的声场。而假如声场仅由一列平面波构成, 那么其 HOA 信号即可用上式直接获得。更为一般的情形, 理论上可以利用球谐函数的正交完备性, 对声压进行积分得到:

$$B_n^m = \frac{1}{i^n j_n(kR)} \int_S p(kR, \theta, \phi) Y_n^m(\theta, \phi) dS \quad \dots\dots (E.8)$$

这一公式描述了空间编码的一般过程。在实际应用中, 一般将展开式截断到某一阶数, 从而对于最高阶数为 N 的情形, 共有 $(N+1)^2$ 个 HOA 信号 B_n^m 。

E.2.3 麦克风阵列全景声录音信号的空间编码方法

首先考虑一个全指向 (omnidirectional) 的麦克风阵列, 这些麦克风可以接收各个方向的声压。假设得到了半径为 R 的球面上的声压分布, 对于一般情形可以由公式 (E.8) 通过积分获得 HOA 信号。然而, 需要注意的是球贝塞尔函数的值与声波频率相关。对于某些特定频率的声波, 使得 $j_n(kR)$ 取到零点, 这一公式将无法求解, 从而无法获得 HOA 信号, 因此, 必须采用某种特定指向性的麦克风阵列以避免零点的情况。考虑一个刚性球体, 其半径为 R , 麦克风阵列均匀分布于球体表面; 利用声波的散射模型可以解出全空间的声场分布:

$$p_{\text{rig}}(kr, \theta, \phi) = \sum_{n=0}^{\infty} i^n b_n(kr) \sum_{m=-n}^n B_n^m Y_n^m(\theta, \phi) \quad \dots\dots (E.9)$$

其中 $b_n(kr)$ 为

$$b_n(kr) = j_n(kr) - \frac{j'_n(kR)}{h'_n(kR)} h_n(kr) = \frac{i}{(kR)^2} \frac{1}{h'_n(kr)} \quad \dots\dots (E.10)$$

式中:

$h_n(kr)$ —— n 阶第一类球汉克尔函数。

这一表达式仅在 $r=0$ 处有一个零点, 因此可以在很宽的频率范围内满足解码的要求, 从而解码过程用积分式可表示为

$$B_n^m = \frac{1}{b_n(kR)} \int_S p(kR, \theta, \phi) Y_n^m(\theta, \phi) dS \quad \dots\dots (E.11)$$

在实际中, 积分是通过离散化的麦克风阵列求和实现的。而为使离散化的球谐函数组作为基函数仍然保持正交性, 麦克风阵列不能任意分布, 而需满足离散化正交条件: 对于方向分别为 $(\theta_1, \phi_1), (\theta_2, \phi_2), \dots, (\theta_Q, \phi_Q)$ 的 Q 个麦克风组成的阵列, 需有

$$\frac{1}{Q} y_n^m \cdot y_{n'}^{m'} = \delta_{mm'} \delta_{nn'} \quad \dots\dots (E.12)$$

式中：

$y_n^m = [Y_n^m(\theta_1, \phi_1), \dots, Y_n^m(\theta_Q, \phi_Q)]$ ——球谐函数组成的向量。

这一正交性的要求与连续情形下球谐函数本身的正交性相对应，因此，麦克风阵列的分布需使得正交性的误差达到最小。

令 $W_n(kR) = |1/b_n(kR)|$ ，在高阶和低频（对应 kR 值较小）的情况下， W_n 对信号的增益幅度过大，在实际应用中这一效应将会使噪声信号放大，从而无法在低频段得到正确的 HOA 信号。另一方面，考虑离散化 HOA 信号的求解，已知麦克风信号及其方位，在 N 阶 HOA 下用矩阵形式表示其声场展开式：

$$\mathbf{s} = \mathbf{B} \cdot \mathbf{T} \quad \dots\dots (E.13)$$

其中 $\mathbf{s} = [s_1, \dots, s_Q]$, $\mathbf{B} = [B_0^0, B_1^{-1}, \dots, B_N^m]$,

$$\mathbf{T} = \mathbf{Y} \cdot \text{diag}\{i^n b_n\} \quad \dots\dots (E.14)$$

其中 $0 \leq n \leq N$,

$$\mathbf{Y} = \begin{bmatrix} Y_0^0(\theta_1, \phi_1) & \dots & Y_N^N(\theta_1, \phi_1) \\ Y_0^0(\theta_2, \phi_2) & \dots & Y_N^N(\theta_2, \phi_2) \\ \vdots & \ddots & \vdots \\ Y_0^0(\theta_Q, \phi_Q) & \dots & Y_N^N(\theta_Q, \phi_Q) \end{bmatrix} \quad \dots\dots (E.15)$$

由此可以得到 $\mathbf{B}$ 的最小二乘解

$$\mathbf{B} = \mathbf{s} \cdot \mathbf{E} \cdot \text{diag}\left[\frac{1}{i^n b_n}\right] \quad \dots\dots (E.16)$$

$$\mathbf{E} = (\mathbf{Y}^T \mathbf{Y})^{-1} \mathbf{Y}^T \quad \dots\dots (E.17)$$

为减小误差，同时也减弱低频响应的增强行为，对 $\mathbf{B}$ 进行正规化，引入一个滤波器 $F_n(kR)$

$$F_n(kR) = \frac{|b_n(kR)|^2}{|b_n(kR)|^2 + \lambda^2} \quad \dots\dots (E.18)$$

$$\mathbf{B}_{REG} = F_n(kR) \cdot \mathbf{B} = \mathbf{s} \cdot \mathbf{E} \cdot EQ_n(kR) \quad \dots\dots (E.19)$$

$$EQ_n(kR) = \frac{\overline{(i^n b_n)(kR)}}{|b_n(kR)|^2 + \lambda^2} \quad \dots\dots (E.20)$$

式中：

Λ ——正规化参数；

$\overline{}$ ——取共轭运算。

这一滤波器的引入可以很好地控制低频增强，但是若其值过大，则会使信号整体幅度偏低，因此需要找到合适的参数值。

综合以上步骤，可以得到基于球形麦克风阵列的全景声录音信号的空间编码的具体流程如图 E.3 所示。

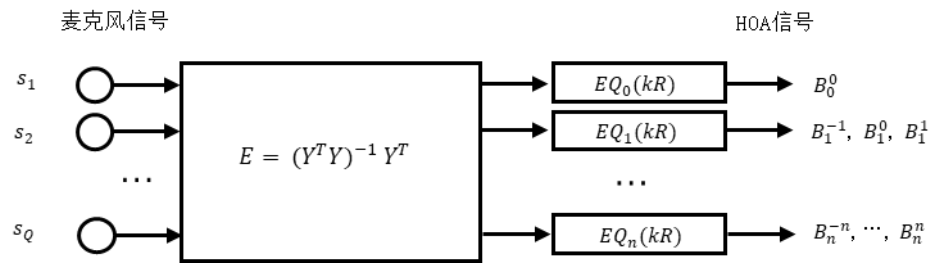


图 E.3 基于球形麦克风阵列的全景声录音信号的空间编码的具体流程

附录 F
(资料性)
场景信号编解码及渲染的通用技术

F.1 场景编解码系统描述

F.1.1 声场采样设备

为了获取完整的声场信息，使用在刚性球体表面均匀分布的麦克风阵列作为声场的采样设备。基于 Ambisonics 原理，阵列采样得到的信号可以编码为场景信号（FOA/HOA 信号），并实现采样声场的重放。

附录 D 给出了一种基于 Ambisonics 全景录音球的麦克风阵列摆放实现方案。

F.1.2 编码器

图F.1给出了场景信号编码器的具体实现。场景信号编码器包括以下主要组成部分：

- 1) 计算HOA阶数：根据采样麦克风阵列的通道数量决定HOA的阶数；
- 2) 计算球谐变换矩阵：利用麦克风的位置信息和HOA的阶数计算球谐变换矩阵；
- 3) 球谐变换：利用球谐变换矩阵对采样信号进行球谐变换；
- 4) 均衡处理：对球谐变换后的系数进行均衡处理，得到HOA信号；
- 5) 压缩编码：对于上述多通道的HOA信号，使用压缩编码算法进一步压缩，得到压缩后的HOA信号位流。

场景信号编码器的编码过程为：根据采样麦克风阵列的麦克风数量、位置信息得到HOA的阶数，根据HOA阶数和麦克风的位置计算球谐变换矩阵。使用球谐变换矩阵对输入信号进行球谐变换，再经过均衡处理得到HOA信号。由于HOA信号之间相关性高，可以选择使用MCR配对或PCA分组的方式进行声道压缩编码，得到压缩后的HOA信号位流。由压缩HOA信号位流和HOA阶数，生成编码位流。

场景信号编码器的输出位流，即场景信号编码位流，由压缩HOA信号位流和HOA阶数组成。场景信号编码器的示意图如图F.1所示：

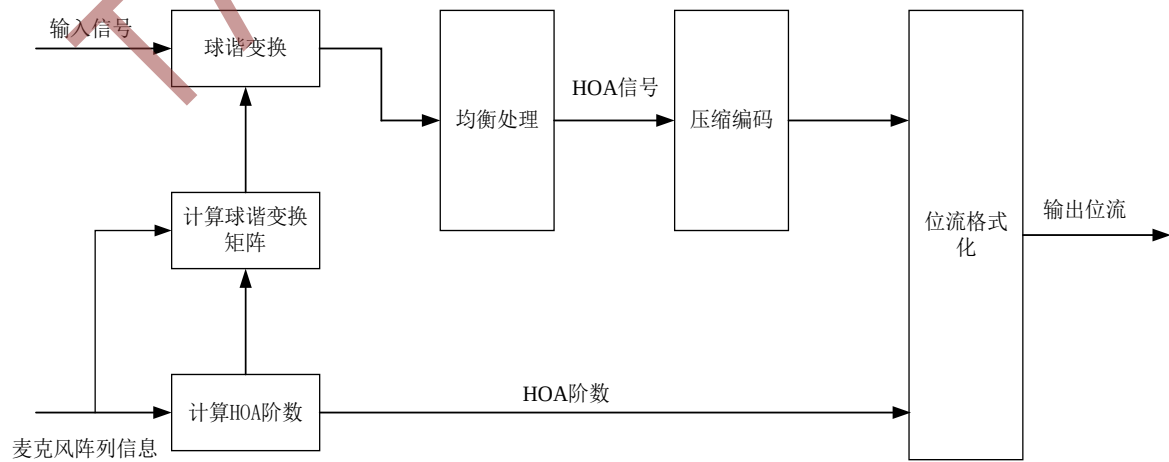


图 F.1 场景信号编码器

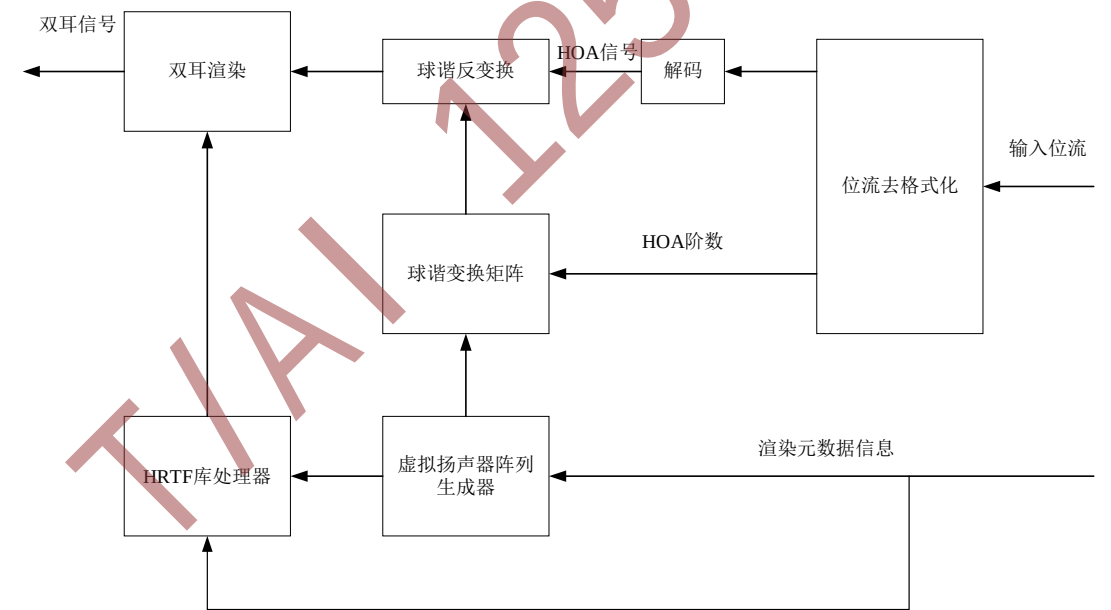
上述场景信号编码器的具体理论在附录E中给出。

F.1.3 解码器

图F.2给出了场景信号解码器的具体实现。场景信号解码器包括以下主要组成部分：

- 1) 位流解复用器：对输入位流进行分解；
- 2) 压缩HOA信号解码器：对位流中的压缩HOA信号进行解码，得到原HOA信号；
- 3) 虚拟扬声器阵列生成器：根据渲染元数据生成一组虚拟扬声器的位置；
- 4) HRTF库处理器：根据渲染元数据选定HRTF库，并选取虚拟扬声器对应方向的HRTF数据用于双耳渲染；
- 5) 计算球谐变换矩阵：根据虚拟扬声器的位置信息和HOA信号的阶数计算球谐变换矩阵；
- 6) 球谐反变换：利用球谐变换矩阵对HOA信号进行HOA反变换；
- 7) 双耳渲染：对HOA反变换后的信号进行双耳渲染，得到双耳信号。

场景信号解码器的输入包括：压缩HOA信号位流、HOA阶数和渲染元数据信息。虚拟扬声器阵列生成器根据渲染元数据生成一组虚拟扬声器的位置，位置信息分别通过HRTF库处理器和球谐函数变换。HRTF库处理器根据渲染元数据选定HRTF库，并选取虚拟扬声器对应方向的数据用于双耳渲染。据虚拟扬声器的位置信息和HOA信号的阶数计算球谐变换矩阵。利用球谐变换矩阵对HOA信号进行HOA反变换，得到虚拟扬声器的增益信号。根据虚拟扬声器的增益信号及其对应的HRTF数据进行双耳渲染，生成双耳信号并输出。场景信号解码器的示意图如图F.2所示：

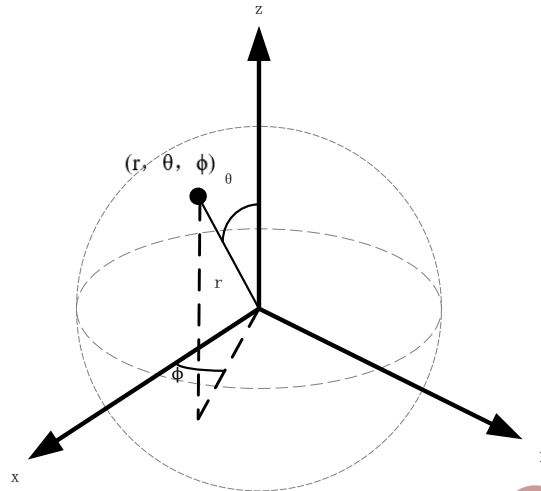


图F.2 场景信号解码器

F.2 基于球谐函数分解的空间编解码原理

F.2.1 球谐函数分解

从基本的声学理论出发,考虑声波在空间内的传播。在图F.3所示的球极坐标系中, r 代表径向, θ 为仰角, ϕ 为水平角。



图F.3 球极坐标系

在球极坐标系下,对于一块不含声源的自由场空间,其内部任意一点 (r, θ, ϕ) 的声压可以由Fourier-Bessel级数表示:

$$p(kr, \theta, \phi) = \sum_{n=0}^{\infty} i^n j_n(kr) \sum_{m=-n}^n B_n^m Y_n^m(\theta, \phi) \quad \dots\dots (F.1)$$

式中:

P ——声压;

$j_n(kr)$ ——第一类球贝塞尔函数;

B_n^m ——隐含时间的系数,又称为HOA信号;

$Y_n^m(\theta, \phi)$ ——表示在水平角 ϕ ,仰角 θ 方向的第 n 阶第 m 级的球谐函数。

此处选取的球谐函数定义规范表示如下:

$$Y_n^m(\theta, \phi) = \sqrt{(2n+1)(2-\delta_{0,m}) \frac{(n-|m|)!}{(n+|m|)!}} P_n^{|m|}(\sin \theta) \times \begin{cases} \sin(-m\phi), & \text{if } m < 0 \\ \cos(m\phi), & \text{if } m \geq 0 \end{cases} \quad \dots\dots (F.2)$$

式中:

P_n^m ——连带勒让德函数。

具体表达式如式(F.3)和(F.4)所示:

$$P_n^m(x) = (1-x^2)^{m/2} \frac{d^m}{dx^m} P_n(x), (m < n) \quad \dots\dots (F.3)$$

$$P_n(x) = \frac{1}{2^l l!} \frac{d^l}{dx^l} (x^2-1)^l \quad \dots\dots (F.4)$$

Dirac函数 $\delta_{n,m}$ 的定义为:

$$\delta_{n,m} = \begin{cases} 1, & n = m \\ 0, & n \neq m \end{cases} \quad \dots\dots (F.5)$$

此处采用的为实球谐函数，而如果选用一般的复球谐函数，也同样成立。这一球谐函数的定义规范被称为N3D。

在实际应用中，一般将展开式截断到某一阶数，对于最高阶数为 N 的情形，共有 $(N+1)^2$ 个球谐函数分量。

F.2.2 基于球谐函数分解的空间编码

编码原理见附录E。

首先根据录音设备的麦克风数量计算HOA编码的阶数，

$$order = \left\lfloor \sqrt{\text{mic_num}} \right\rfloor$$

根据HOA阶数计算得到HOA信号通道数，并通过麦克风的位置得到其方向 (θ_i, ϕ_i) ，利用公式(E.2)计算对应的球谐函数系数。根据附录E公式(E.14)得到由麦克风球谐函数系数组成的矩阵 $\mathbf{Y}$ 。再对麦克风信号进行球谐函数变换，根据附录E公式(E.15)得到音频的球谐函数域表示。将各个通道的球谐函数信号变换到频域，根据公式(E.10)和(E.16)计算均衡后的径向函数系数。最后对频域的音频球谐域表示进行均衡处理，得到均衡后的频域HOA信号

场景数据的编码过程伪代码描述如下：

```

hoa_ch_num = (order + 1) × (order + 1)
for ( i = 0; i < mic_num; i++ )
    计算mic_harms[i][0..hoa_ch_num-1]
for ( i = 0; i < frame_length; i++ )
    sph_coef[i][0..hoa_ch_num-1] =  $\mathbf{s} \cdot \mathbf{E}$ 
for ( i = 0; i < hoa_ch_num; i++ )
    sph_coef_fq[0..frame_length-1][i][0..1] = fft ( sph_coef[0..frame_length-1][i] )

fn[0..frame_length/2][0..hoa_ch_num-1][0..1] =  $\frac{(i^n b_n)^*(kR)}{|b_n(kR)|^2 + \lambda^2}$ 

for ( i = 0; i < frame_length/2; i++ )
    hoa_coef_fq [i][0..hoa_ch_num-1][0..1] =
        sph_coef_fq[i][0..hoa_ch_num-1][0..1] .* fn[i][0..hoa_ch_num-1] [0..1]
for ( i = 0; i < hoa_ch_num; i++ )
    hoa_sig[0..frame_length-1][i] = ifft ( hoa_coef_fq[0..frame_length-1][i][0..1] )
其中，

```

$\mathbf{s}$ 是麦克风信号， $\mathbf{E}$ 根据公式(E.15)由 $\mathbf{Y}$ 计算，“ $\cdot$ ”表示对应通道的复数乘法；sph_coef_fq中第三维的两个数据分别存储频域数值的实部和虚部。hoa_coef_fq的后一半系数通过共轭对称的方式由前一半系数得到。将hoa_coef_fq变换到时域，得到时域HOA信号。

对这一时域HOA信号，根据进一步压缩的要求，可以使用不同的算法进行压缩编码。

F.2.3 基于球谐函数分解的空间解码

空间解码的原理是通过平面波的叠加恢复原始声场的HOA信号。考虑 L 列平面波叠加的情况,假设 L 列平面波的传播方向分别为 (θ_l, ϕ_l) ($l=1, 2, \dots, L$)。则每列平面波产生的声场 S_l 可以表示如公式(F.6)所示:

$$S_l = \sum_{n=0}^{\infty} i^n j_n(kr) \sum_{m=-n}^n s_l Y_n^m(\theta, \phi) Y_n^m(\theta_l, \phi_l) \quad \dots\dots (F.6)$$

式中:

s_l ——每列平面波的幅度。

对于每列平面波,其HOA信号可以表示为:

$$B_{n,l}^m = s_l Y_n^m(\theta_l, \phi_l) \quad \dots\dots (F.7)$$

使用平面波的HOA信号叠加得到目标声场的HOA信号可用式(F.8)表示:

$$B_n^m = \sum_{l=1}^L B_{n,l}^m = \sum_{l=1}^L s_l Y_n^m(\theta_l, \phi_l) \quad \dots\dots (F.8)$$

在阶数为 N 的情况下,式(F.5)可以写为矩阵的形式:

$$\mathbf{B} = \mathbf{C} \cdot \mathbf{S} \quad \dots\dots (F.9)$$

$$\mathbf{C} = \begin{bmatrix} Y_0^0(\theta_1, \phi_1) & \dots & Y_0^0(\theta_L, \phi_L) \\ \vdots & \ddots & \vdots \\ Y_N^N(\theta_1, \phi_1) & \dots & Y_N^N(\theta_L, \phi_L) \end{bmatrix} \quad \dots\dots (F.10)$$

式中:

$\mathbf{B} = [B_0^0, B_1^{-1}, \dots, B_N^N]^T$ ——一个 $(N+1)^2$ 维的向量。

由此可得各平面波的振幅可以表示为:

$$\mathbf{S} = \text{pinv}(\mathbf{C}) \cdot \mathbf{B} = (\mathbf{C}^* \cdot \mathbf{C})^{-1} \cdot \mathbf{C}^* \cdot \mathbf{B} \quad \dots\dots (F.11)$$

式中:

$\mathbf{C}^*$ —— $\mathbf{C}$ 的共轭转置。

式(F.7)中得到的 $\mathbf{S}$ 为各平面波振幅的最小二乘解。当平面波的方向分布不均匀时,会导致矩阵 $\mathbf{C}$ 的条件数过大,而引起重构声场的不稳定。因此,在选择平面波的方向时应当尽量均匀分布在空间各个方向。

F.3 场景信号解码与双耳渲染

F.3.1 HOA信号到虚拟扬声器的解码

对于场景声场的HOA信号,基于上述空间解码原理,进行解码。在这里引入虚拟扬声器,虚拟扬声器均匀分布于人头的四周各个方向,每个虚拟扬声器对应于一列特定方向传播的平面波。考虑到虚拟扬声器的均匀性要求,以及进行HOA编解码时常用的HOA阶数,这里选择正12面体的20个顶点位置所对应的空间方向作为虚拟扬声器的方位,坐标原点设置在正12面体的几何中心。当虚拟扬声器的数量继续增加时,无法找到完全均匀的分布方式。

虚拟扬声器均匀分布在距离坐标原点半径为1米的球面上,各个位置的元数据坐标如表F.1所示。

表F.1 虚拟扬声器建议摆放位置

序号	x/m	y/m	z/m
1	0	φ	$1/\varphi$
2	0	φ	$-1/\varphi$
3	0	$-\varphi$	$1/\varphi$
4	0	$-\varphi$	$-1/\varphi$
5	$1/\varphi$	0	φ
6	$1/\varphi$	0	$-\varphi$
7	$-1/\varphi$	0	φ
8	$-1/\varphi$	0	$-\varphi$
9	φ	$1/\varphi$	0
10	φ	$-1/\varphi$	0
11	$-\varphi$	$1/\varphi$	0
12	$-\varphi$	$-1/\varphi$	0
13	1	1	1
14	1	1	-1
15	1	-1	1
16	1	-1	-1
17	-1	1	1
18	-1	1	-1
19	-1	-1	1
20	-1	-1	-1
注：表中 $\varphi = (1 + \sqrt{5})/2$			

假设 20 个虚拟扬声器对应的平面波的传播方向分别为 (θ_l, ϕ_l) ($l=1, 2, \dots, 20$)，它们与虚拟扬声器的方向矢量恰好反向。则由式 (F.6) 可以求得 **C** 矩阵。

球形麦克风阵列实录信号编码后得到的 HOA 信号为 **B**。为了重构出相应的 HOA 信号，20 个虚拟扬声器需要分配的增益为 g_l ($l=1, 2, \dots, 20$)，令 $\mathbf{G}=[g_1, g_2, \dots, g_{20}]^T$ ，则由式 (F.7) 可以求得各个虚拟扬声器的增益如下：

$$\mathbf{G} = (\mathbf{C}^* \cdot \mathbf{C})^{-1} \cdot \mathbf{C}^* \cdot \mathbf{B} \quad \dots\dots (F.12)$$

HOA信号到虚拟扬声器的解码过程伪代码如下：

```
hoa_ch_num = (order+1) × (order+1)
for ( n = 0; n <= order; n++ )
    for ( m = -n; m <= n; m++ )
        for ( l = 0; l < spk_num; l++ )
            spk_harms[n×n+m+n][l] = getSphHarm (spk_pos[l][0..2] )
for ( t = 0; t < frame_length; t++ )
```

$$\text{spk_gains}[t][0..(\text{spk_num}-1)] = \text{HOAInvTrans}(\text{hoa_sig}[t][0..(\text{hoa_ch_num}-1)], \text{spk_harms}[0..(\text{hoa_ch_num}-1)][0..(\text{spk_num}-1)])$$

其中,

`getSphHarm()` 是计算球谐函数系数的子函数, 函数首先将扬声器的元数据坐标转换为球极坐标系下的方向, 再根据扬声器的方向由公式 (F.2) 计算得到扬声器对应的球谐函数系数。

`HOAInvTrans()` 是进行HOA反变换的子函数, 是公式 (F.7) 的算法实现。

F.3.2 虚拟扬声器信号的双耳渲染

虚拟扬声器信号到双耳的渲染由HRTF技术实现。

HRTF库中包含了自由声场中测量位置处到人双耳处的声学传输函数, 其对应的时域信号为头相关脉冲响应。

由式 (F.8) 计算得到的虚拟扬声器增益在时间上展开, 每个虚拟扬声器对应的时域离散信号记为 $g_l[n]$, HRTF库中与虚拟扬声器对应方向的左右耳HRIR分别记为 $h_l^L[n]$, $h_l^R[n]$ 。则一个虚拟扬声器的信号到人双耳信号的渲染可以用式 (F.13) 和 (F.14) 表示:

$$L_l[n] = g_l[n] \otimes h_l^L[n] \quad \dots\dots (F.13)$$

$$R_l[n] = g_l[n] \otimes h_l^R[n] \quad \dots\dots (F.14)$$

式中:

$\otimes$ ——离散信号的时域卷积。

根据声波的叠加原理, 所有虚拟扬声器信号到双耳信号的渲染公式为:

$$L[n] = \sum_{l=1}^{20} L_l[n] \quad \dots\dots (F.15)$$

$$R[n] = \sum_{l=1}^{20} R_l[n] \quad \dots\dots (F.16)$$

虚拟扬声器信号的双耳渲染过程的伪代码如下:

```

hrir_spk[0..(spk_num-1)][..][0..1] = loadHrir(spk_pos[0..(spk_num-1)])
for ( l = 0; l < spk_num; l++)
    for ( ch = 0; ch < 20; ch++)
        sig_spk[l][..][ch] = conv(spk_gains[..][l], hrir_spk[l][..][ch])
sig_binaural[..][0..1] = 0
for ( l = 0; l < spk_num; l++)
    for ( ch = 0; ch < 20; ch++)
        sig_binaural[..][ch] += sig_spk[l][..][ch]

```

其中`loadHrir()` 是根据虚拟扬声器位置选取HRIR数据的子函数, `conv()` 是实现离散信号线性卷积的子函数。

附录 G
(资料性)
多通道音频生产系统规范建议及测试方案

G.1 应用范围

附录 G 对音频制作系统的关键性指标提出建议规范以及测试方案，从制作工具上对多通道音频的生产制作给出指导建议。

G.2 方案背景

从技术流程上来看，多通道音频技术流程分为采集，编解码传输，渲染回放三个部分。其中多通道音频生产系统的性能对于多通道音频的采集至关重要。在实际多通道音频采集及制作中，由于生产及采集系统在一些音频特性上不够规范，进而导致制作出来的音频难以满足后续编解码以及回放的质量要求。附录 G 基于多通道音频采集及制作的实际经验出发，对于多通道音频生产系统中关键指标做出了建议，同时提供了具体测试步骤和验证方案。图 G.1 三维声录制系统为附录 G 所测量的系统部分。

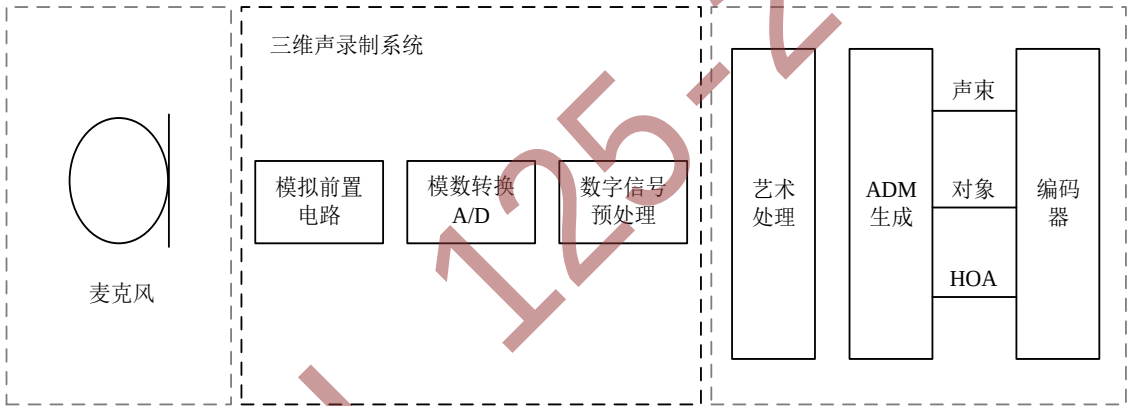


图 G.1 多通道音频采集框图

G.3 生产系统指标以及测试方案

G.3.1 录音设备灵敏度

G.3.1.1 要求

录音输入路径应当使用数字信号的有效全部动态范围，例如 16 比特数据使用 15 比特全部有效范围，以此来减少噪声和音频失真。数字的动态范围应该能满足痛域声压 $120\text{dB SPL} = 26\text{ dB Pa}$ 条件下，总谐波失真小于 3% 的要求。录音设备需要保证信号幅度的线性变化以及在最大幅度时不能出现二进制反转问题。

G.3.1.2 测试规程

G.3.1.2.1 测试环境配置

测试环境配置如表 G.1 所示：

表 G. 1 测试环境配置

测试对象	内容
测试信号	1KHz 1dB 步进测试单音文件
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	-

G. 3. 1. 2. 2 测试关键步骤以及测试信号校准

测试关键步骤以及测试信号校准步骤如下：

1) 测试输入设备产生输入信号的最大幅度 $U_{max,dBV}$ 应该等效于最大声压 120dB SPL 情况下，录音系统所使用麦克风产生的最大电压信号。该最大幅度 $U_{max,dBV}$ 可以通过如下公式计算得到：

$$U_{max,dBV} = 26\text{ dBPa} + s_{dBV/Pa} \dots\dots (G.1)$$

$$U_{max,V} = 20Pa * s_{V/Pa} \dots\dots (G.2)$$

式中：

s ——麦克风灵敏度。

2) 在测试中，本文件所提供的测试信号为以 1dB 步进的数字信号，测试者需要保证该步进信号的最后一个步进音频信号（0dBFS PK）的输出电压值等于 $U_{max,dBV}$ ；

3) 测试输入设备播放测试信号，并在测试结果信号录入节点记录测试数据。

G. 3. 1. 2. 3 测试结果分析

运行分析脚本，脚本将分析结果以图表的方式输出，该图表将包含信号的线性度以及总谐波失真。

G. 3. 2 录音系统频率响应

G. 3. 2. 1 要求

根据本文件音频编解码对 LC（低复杂度）文件的规定，多通道音频原始最大支持采样率如表 G.2 所示。

表 G. 2 多通道音频原始最大支持采样率

文件等级	最大采样率 kHz	激励信号
1	48	采样率 48KHz, 0~24KHz 的扫频信号
2	48	采样率 48KHz, 0~24KHz 的扫频信号
3	48	采样率 48KHz, 0~24KHz 的扫频信号

表 G. 2（续）

文件等级	最大采样率 kHz	激励信号
4	48	采样率 48KHz, 0~24KHz 的扫频信号
5	96	采样率 96KHz, 0~48KHz 的扫频信号

对于所支持的文件等级，录音系统需满足该等级所要求最大采样率，参考倍频程滤波器指标规范，按照 1/3 倍频程得到两种采样率下对应系统频率响应指标，如表 G.3 和表 G.4 所示：

表 G. 3 采样率 48KHz 音频系统频率响应指标

频率（Hz）	上限（dB）	下限（dB）
0	1	-Inf
50	1	-5
100	1	-1
18000	1	-1
22500	1	-5
24000	1	-Inf

表 G. 4 采样率 96KHz 音频系统频率响应指标

频率（Hz）	上限（dB）	下限（dB）
0	1	-Inf
50	1	-5
100	1	-1
36000	1	-1
45000	1	-5
48000	1	-Inf

G. 3. 2. 2 测试规程

G. 3. 2. 2. 1 测试配置

测试配置如表 G.5 所示：

表 G. 5 测试配置

测试对象	内容
测试信号	扫频测试文件

表 G.5 （续）

测试对象	内容
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	-

G.3.2.2.2 测试关键步骤以及测试信号校准

测试关键步骤以及测试信号校准步骤如下：

- 1) 测试输入设备播放测试信号，并在测试结果信号录入节点记录测试数据；
- 2) 使用分析脚步载入测试数据，运行分析脚本；
- 3) 运行脚本将给出频率响应曲线。

G.3.2.2.3 测试结果分析

测试结果分析步骤如下：

- 1) 测试输入设备播放测试信号，并在测试结果信号录入节点记录测试数据；
- 2) 使用分析脚步载入测试数据，运行分析脚本；
- 3) 运行脚本将给出频率响应曲线。

G.3.3 录音系统信号完整度

G.3.3.1 要求

录音系统在录制多通道音频时，不应引入任何形式的音频数据丢失，从而导致音频数据不连续。

G.3.3.2 测试规程

G.3.3.2.1 测试配置

测试配置如表 G.6 所示：

表 G.6 测试配置

测试对象	内容
测试信号	扫频测试文件
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	无，使用第三方工具查看

G.3.3.2.2 测试关键步骤以及测试信号校准

测试输入设备播放测试信号，并在测试结果信号录入节点记录测试数据。

G.3.3.2.3 测试结果分析

使用第三方工具查看有无数据丢失。

G.3.4 录音系统电子底噪

G.3.4.1 要求

录音系统电子底噪是衡量录音系统在无信号输入时的电子噪声能量大小。该指标以信号信噪比 SNR 来表示，其含义为：假设输入有效信号为 0dBFSpk，考虑到 120dBSPL 为最大声压，实际录音中考虑有效声音响度分布，一般以 110dBSPL 对应于 0dBFS，当前主流麦克风的电子底噪等效声压分布在 30dBSPL 左右，该等效声压对应于-80dBFS。所以系统的底噪应该以 80dBFS 为基准（低于 80dBFS 将淹没在麦克风的电子噪声里，性价比不高），所以建议录音系统的电子底噪 SNR 应该大于 80dB。

G.3.4.2 测试规程

G.3.4.2.1 测试配置

测试配置如表 G.7 所示：

表 G.7 测试配置

测试对象	内容
测试信号	无
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	-

硬件设置：断开麦克风连接，麦克风接口连接相应的匹配电阻与电容，以此将麦克风连接模拟作为电路负载。

G.3.4.2.2 测试关键步骤以及测试信号校准

测试关键步骤以及测试信号校准步骤如下：

- 1) 在测试结果信号录入节点记录测试数据；
- 2) 确保测试信号无丢包现象；
- 3) 使用分析脚本载入测试数据，运行分析脚本。

G.3.4.2.3 测试结果分析

查看脚本运行结果，判断测试结果通过与否。

G.3.5 录音系统声道相对延迟

G.3.5.1 要求

作为多通道音频录音系统，在以多声道模式制作多通道音频时，要求声道之间不应该引入额外的延迟，同时声道之间的延迟不应该有任何波动。

G.3.5.2 测试规程

G. 3. 5. 2. 1 测试配置

测试配置如表 G.8 所示：

表 G. 8 测试配置

测试对象	内容
测试信号	白噪声测试信号
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	-

G. 3. 5. 2. 2 测试关键步骤以及测试信号校准

测试关键步骤以及测试信号校准步骤如下：

- 1) 测试输入设备播放测试信号，并在测试结果信号录入节点记录测试数据；
- 2) 使用分析脚本载入测试数据，运行分析脚本。

G. 3. 5. 2. 3 测试结果分析

查看脚本运行结果，判断测试结果通过与否。

G. 3. 6 录音系统声道串扰

G. 3. 6. 1 要求

作为多通道音频录音系统，在以多声道模式制作多通道音频时，要求在有效频带上，对声道串扰的压制超过 60dB（此数值参考当今主流音频测试厂商建议的指标）。

G. 3. 6. 2 测试规程

G. 3. 6. 2. 1 测试配置

测试配置如表 G.9 所示：

表 G. 9 测试配置

测试对象	内容
测试信号	扫频信号
测试输入设备	声卡，或者音频产生设备
测试信号输入节点	麦克风信号接入点
测试结果信号录入节点	原始音频信号存储节点
分析脚本	-

硬件设置：假设录音系统有 N 个声道，在测量第 i 个声道时，断开除第 i 声道外其他声道所对应的麦克风连接，断开的接口连接相应的匹配电阻与电容，以此将麦克风连接模拟作为电路负载。

G. 3. 6. 2. 2 测试关键步骤以及测试信号校准

测试关键步骤以及测试信号校准步骤如下：

- 1) 按照上述硬件设置配置第一声道对其他声道的串扰，输入激励信号，并记录测试结果；
- 2) 重复上述步骤，直至所有声道测量完成；
- 3) 确保测试信号无丢包现象；
- 4) 使用分析脚步载入测试数据，运行分析脚本。

G. 3. 6. 2. 3 测试结果分析

查看脚本运行结果，判断测试结果通过与否。

T/AI 125-2023

附录 H

(资料性)

基于头相关传输函数的 3DoF 三维音频渲染器

H.1 背景

附录 H 针对虚拟现实音频输入格式中解码后的声道信号,可将其渲染成适合耳机回放的双声道音频,同时支持垂摇(Yaw)、纵摇(Pitch)和横摇(Roll)三种自由度(3DoF)的动态渲染。并支持使用个性化 HRTF 参数,不同空间分辨率的 HRTF 库。

H.2 技术框架

附录 H 实现了对声道信号渲染到三维音频的功能,通过对解码后的声道信号分段处理,可以支持头部姿态变换时的动态渲染。考虑到不同应用场景需要,支持 SOFA 格式的自定义 HRTF 库,并在最后引入 AGC 声音增益,具体技术框图如图 H.1 所示。

实现该技术框架的步骤如下:

- 1) 首先读取 SOFA 格式的 HRTF 数据库,存储其中各角度的 HRIR 数据。读取解码后为 pcm 码流的 Channel 信号,将数据分段,并逐段处理。其中 SOFA 格式为 AES 协会定义的 HRTF 存储格式,可在 <https://www.sofaconventions.org/mediawiki/index.php/Files> 下载相关的 HRTF 数据库;
- 2) 在每段处理结束时根据陀螺检测头部姿态是否在 Yaw, Pitch, Roll 轴变化,根据得到的变化角度进行式 (H.1) 的坐标转换。

$$\begin{bmatrix} n_x^2(1-\cos\alpha)+\cos\alpha & n_x n_y(1-\cos\alpha)+n_z \sin\alpha & n_x n_z(1-\cos\alpha)-n_y \sin\alpha \\ n_x n_y(1-\cos\alpha)-n_z \sin\alpha & n_y^2(1-\cos\alpha)+\cos\alpha & n_y n_z(1-\cos\alpha)+n_x \sin\alpha \\ n_x n_z(1-\cos\alpha)+n_y \sin\alpha & n_y n_z(1-\cos\alpha)-n_x \sin\alpha & n_z^2(1-\cos\alpha)+\cos\alpha \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} \quad \dots\dots (H.1)$$

式中:

α ——绕轴变化的角度;

(x, y, z) ——左手系下的元数据坐标;

(x', y', z') ——旋转后坐标。

实际使用时,按照 Yaw, Pitch, Roll 轴的旋转角度依次使用式 (H.1) 中的公式去计算旋转后的坐标,三次迭代后得到最终的 (x', y', z') 坐标。

将最终 (x', y', z') 坐标按式 (H.2) 中的公式转换为球极坐标系以使用对应位置的 HRIR 数据,其中由于使用的 HRTF 库都是固定球面上的位置,所以只需要计算球极坐标系中的 θ 和 ϕ 变量。

$$\begin{cases} \theta = \arccos \frac{z'}{\sqrt{x'^2 + y'^2 + z'^2}} \\ \phi = \arctan \frac{y'}{x'} \end{cases} \quad \dots\dots (H.2)$$

根据结果读取新位置对应的 HRIR，作为当前的 HRIR。如果不变，仍使用当前位置的 HRIR。

- 3) 使用对应坐标的左右耳 HRIR 数据与 PCM 数据做卷积，分别将卷积结果相加，将求和结果除以幅值系数，得到双声道数据。为保持动态渲染时的数据连续，再将双声道数据经过 Savitzky-Golay 滤波器处理。同时由于 HRIR 值往往比较小，卷积结果因此变小，所以最后使用 AGC 增益控制来增大声音。

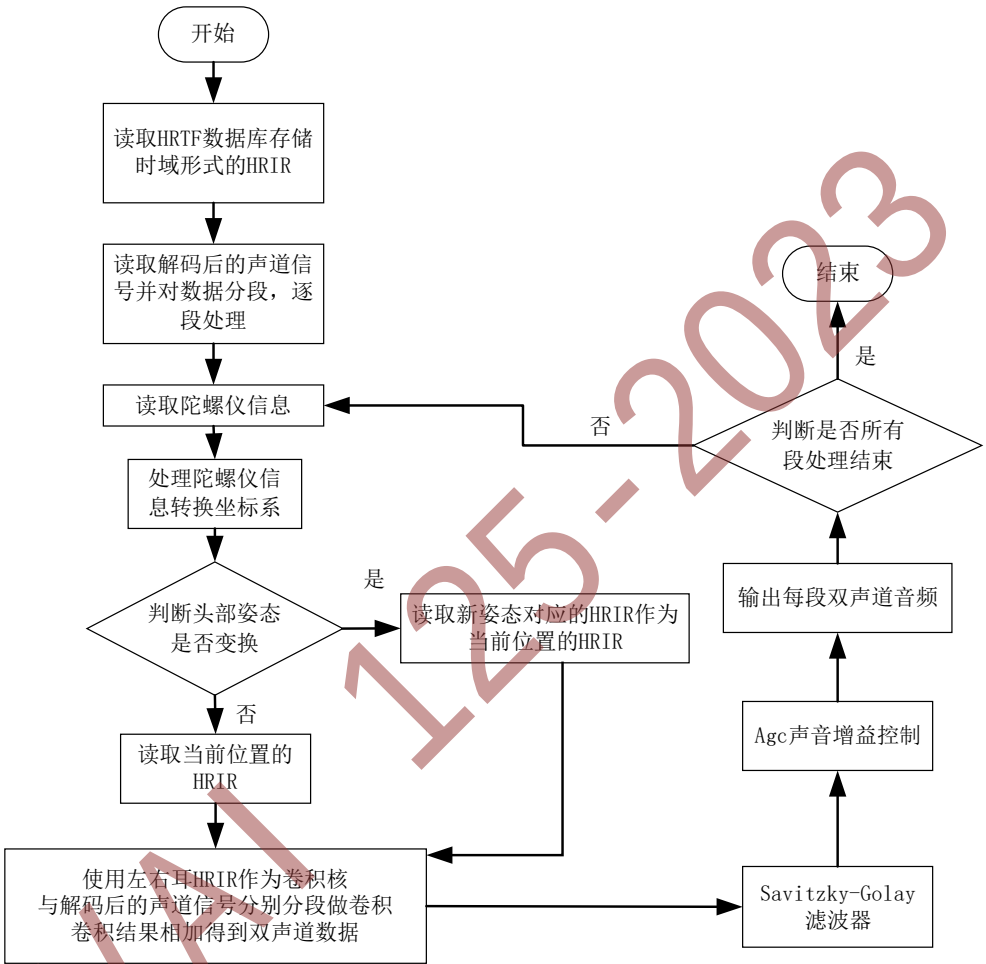


图 H.1 多声道到双声道的三维音频渲染器技术框架

H.3 具体算法

H.3.1 Savitzky-Golay 滤波器

考虑一组以 $n=0$ 为中心的 $2M+1$ 个数据。可以用式 (H.3) 来拟合它：

$$p(n) = \sum_{k=0}^N a_k n^k \quad \dots\dots (H.3)$$

最小二乘拟合的残差如式 (H.4)：

$$\varepsilon_N = \sum_{n=-M}^M (p(n) - x[n])^2 = \sum_{n=-M}^M \left(\sum_{k=0}^N a_k n^k - x[n] \right)^2 \quad \dots\dots (H.4)$$

为获得拟合多项式的常数项，可以对原始数据进行一次 FIR 滤波，即可以利用卷积运算来实现：

$$y[n] = \sum_{m=-M}^M h[m]x[n-m] = \sum_{m=n-M}^{n+M} h[n-m]x[m] \quad \dots\dots (H.5)$$

为使 ε 最小， ε 对各个参数的偏导数应为 0，即：

$$\frac{\partial \varepsilon_N}{\partial a_i} = \sum_{n=-M}^M 2n^i (p(n) - x[n]) = \sum_{n=-M}^M 2n^i \left(\sum_{k=0}^N a_k n^k - x[n] \right) = 0 \quad \dots\dots (H.6)$$

化简后可得：

$$\sum_{k=0}^N \left(\sum_{n=-M}^M n^{i+k} \right) a_k = \sum_{n=-M}^M n^i x[n], i = 0, 1, \dots, N \quad \dots\dots (H.7)$$

通过求得系数向量，可以对输入数据进行加权平均，平滑前后两端数据。

H. 3. 2 AGC增益控制

AGC 增益控制的实现步骤如下：

1) 设置目标音量值与模块的最大增益能力值，计算增益表，增益表即对输入信号能量值（幅值的平方）量化的过程。量化的方法为采用 $y = \log_2 (1 + e^x)$ 进行非均匀量化。增益表的长度为 32，即表示是一个 int 型数据的 32 位（short 型数据的能量值范围为 [0, 32768^2] 可以用无符号 int 型数据表示），从高位到低位，为 1 的最高位具有最大的数量级称为整数部分，后续数位组成小数部分。因此 [0, 32768] 之间的任意一个数都对应数字增益表中的一个增益值。

2) 根据输入信号包络在增益表中查找增益值，并应用增益到输入信号；基于人耳的听觉曲线，AGC 中在应用增益是分段段的，比如一帧 160 个样本点会分为 10 段，每段 16 个样本点，因此会引入分段增益数组，先计算整数部分与小数部分，再通过增益表组合计算出新的增益值，其中就包含了小数部分的补偿。

3) 根据分段增益数组，右移 16 位后获得实际的增益值，直接乘到输出信号上。由此实现 [0, 32768] 中的任何一个数想要增益指定的分贝且结果又不超过 32768，都能在数字增益表中找到确定的元素满足这个要求。

附 录 I

(资料性)

智能电视音箱环绕立体声系统

1.1 概述

随着人工智能和物联网技术的日益成熟，以及智能电视、智能音箱的普及，人们对影音娱乐活动的需求也逐渐提升。为了创造具有沉浸感的听音体验，在音频源上需要环绕声片源，在设备要求上需要特定的环绕声设备。传统的环绕声设备需要有线连接而且价格非常昂贵，环绕声片源指其中的音源包含多通路信息，目前主流的片源多为立体声，5.1 及以上的片源占比非常稀少。

为了让用户在家庭场景下达到近似影院的视听效果，附录 I 针对当前家庭用户可能存在的设备做了设备联动，让智能电视和多台智能音箱组合或者只依靠多台智能音箱组合成家庭环绕声或立体声系统，对多种格式的片源做不同的上混算法得到目标设备的音频，得到更优质的声音、更宽阔的音场，满足所有音频的环绕声和立体声的听音体验。

智能电视音箱环绕立体声系统的目的主要是结合电视（可以支持非智能电视、全频主音箱）和智能音箱，以较低的成本完成全景音频输出，提升家庭影院视听空间感及环绕感，可以让观众从音频上感受目标动态变化，为虚拟现实沉浸式音频提供支持。

重点在于对于多通道不同格式音乐源提取环绕声信息，达到家庭影院的效果；与 5.1 声道下混到 2.0 声道不同，附录 I 技术是在保证原始音频信息不变的情况下增加环绕声信息，在更多的位置播放出来，提升氛围感。

1.2 技术方案实现

1.2.1 技术框架

附录 I 技术方案提供一种智能电视与智能音箱组合播放环绕声/立体声的方案。算法上可以总结为两种信号处理方法，其一，输入信号不包含环绕声信息，附录 I 技术方案将提供一种对多类型音频信号向上混合的方法。内容包括：从所述音频信号中提取出环绕声信号，对环绕声信号进行去相关处理，将原始音频信号和经过去相关处理的环绕声信号呈现为经过向上混合的音频信号；其二，输入信号包含环绕声信息，当前方案支持 L（左声道）、R（右声道）、Ls（左环绕声道）、Rs（右环绕声道）、C（中间声道）、Ltop（左上声道或左天空声道）、Rtop（右上声道或右天空声道）、Low Frequency（低音声道）等，各种实际应用组合，上混或下混合到 2 或 4 个音箱环绕声道或立体声声道信息。在电视按自身策略播放音频时，外置的智能音箱通过算法提取的环绕声信息并播放，达到沉浸式环绕效果。

其中上混是指上混后的信号通道数大于原始信号通道数，例如 2.0 上混到 4.0；下混是指下混后的信号通道数小于原始信号通道数，例如 5.1 下混到 2.1 声道。

最后，附录 I 技术方案提供一种智能电视与智能音箱组合播放环绕声的系统。该系统包括：环绕声提取器，其从原始音频信号中提取出环绕声信号；去相关器，其将环绕声信号进行去相关处理；音频呈现器（智能电视与智能音箱）。

对于立体声和环绕声的切换可以根据用户喜好自动切换，系统也可对音箱和电视的相对位置自动检测，实现相对位置的确认，自动切换适合播放环绕声或是立体声。在自动组网过程中，电视音箱环绕立体声系统也可完成声道自动检测，自动完成通道配置，无需用户手动

完成。
输入模式说明如表 I.1 所示。

表 I.1 电视端输入的信号模式

模式	声道说明							
	左	右	左环绕	右环绕	中置	左上前	右上前	低频效果
1.0	√	×	×	×	×	×	×	×
2.0	√	√	×	×	×	×	×	×
2.1	√	√	×	×	×	×	×	√
2.0.2	√	√	×	×	×	√	√	×
2.1.2	√	√	×	×	×	√	√	√
3.0	√	√	×	×	√	×	×	×
3.0.2	√	√	×	×	√	√	√	×
3.1.2	√	√	×	×	√	√	√	√
4.0	√	√	√	√	×	×	×	×
5.0	√	√	√	√	√	×	×	×
5.1	√	√	√	√	√	×	×	√
5.1.2	√	√	√	√	√	√	√	√

注：表格中插入√的代表输入含有该通道数据输入。

技术方案框架如图 I.1：

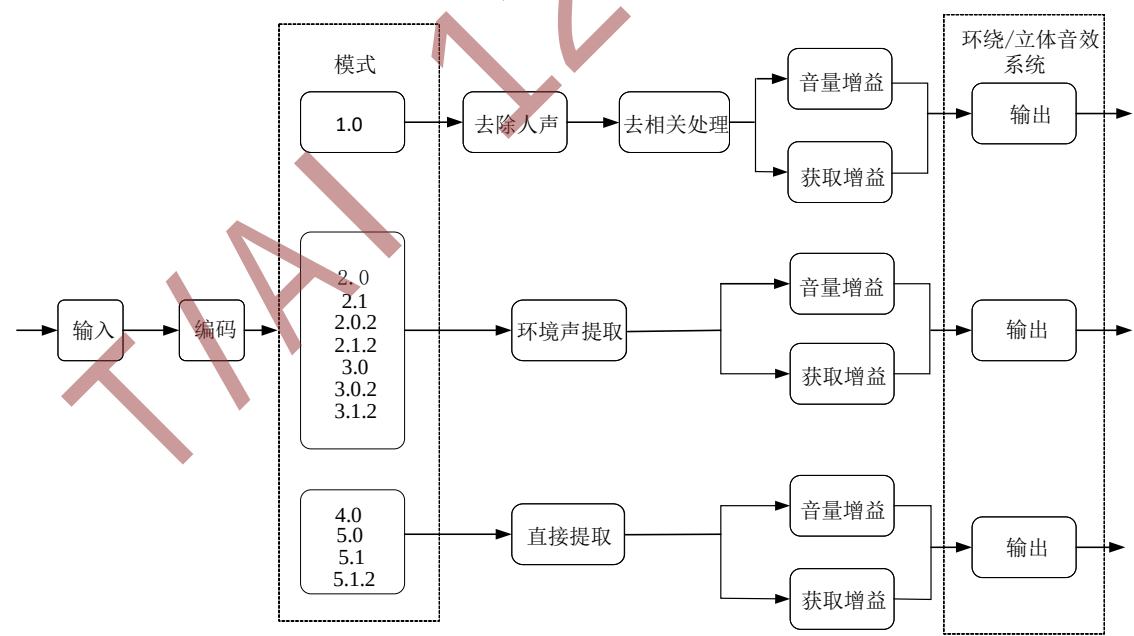


图 I.1 智能电视音箱环绕立体声系统流程框图

I.2.2 预处理

电视端声道先通过解码器解码，以某一种音效处理方式为例，解码得到的 10 个信道输入信号如表 I.2：

表 1.2 电视端解码后前 10 个输入信道内容

通道	声道输入	解码结果
0	L	左
1	R	右
2	Ls	左环绕
3	Rs	右环绕
4	C	中置
5	Ltop	左上前
6	Rtop	右上前
7	Lfe	低频效果
8	DMX_L	左下混声道
9	DMX_R	右下混声道

检测每个信道是否有信号后得到一个标记值给到系统判断是单声道、立体声还是多通道输入。通过输入信号类型选择不同模式进行环绕声提取后得到新的环绕声于通道 10、11 输出：

表 1.3 电视端 decoder 后环绕输入信道内容

通道	声道输入	解码结果
10	Ls	音箱左环绕
11	Rs	音箱右环绕

上混的三种方法在 I.2.4，I.2.5，I.2.6 小节中展开描述。

1.2.3 时延情况说明

该方案涉及多通道回放情况，因此为了不影响听感，分析不同音频格式情况下的时延如表 I.4：

表 1.4 不同音频格式下时延分析

算法方案	音频模式	算法输出多通道时延	分析说明
单通道信号输入	1.0	无	本帧信号滤波直接输出
多声道无环绕信号输入	2.0 2.1 2.0.2 2.1.2 3.0 3.0.2 3.1.2	无	上帧信号与下帧信号一起处理输出，音频信号无输出时延，但是音画同步时延为帧长/采样率，例如 $512/48000=0.0107S$
多声道有环绕信号输入	4.0 5.0 5.1 5.1.2	无	直接放到对应输出

1.2.4 单声道信号输入

单声道信号输入流程如图I.2所示：

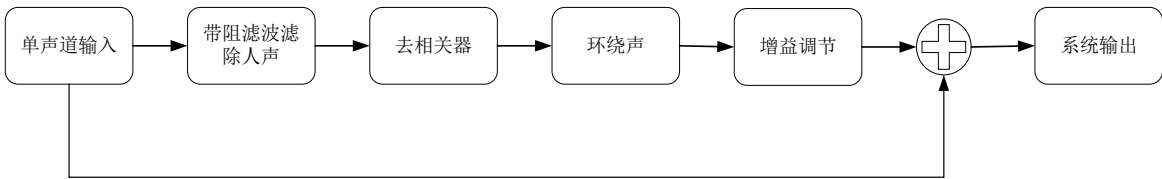


图 I.2 单声道信号输入流程图

单声道输入情况，考虑语音存在的频带范围，设置带阻滤波器，滤除人声，得到环绕声信息。

考虑左右声道的不相关性，去相关频响和相位响应如图 I.3，再对得到的环绕声信息进行去相关处理。

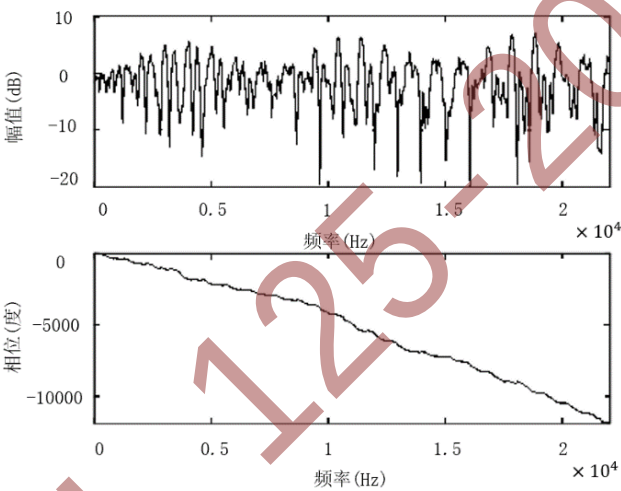


图 I.3 去相关后的频响和相位响应

1.2.5 多声道无环绕信号输入

目前可用的大部分音频内容都是双声道立体声格式。在立体声上混过程中，需要区分主声源和环境。主声源由可定位的声音事件组成，上混的通常目标是保持主声源的相对位置并增强其空间图像稳定性。另一方面，环境由混响或其他空间分布的声源组成。立体声扬声器系统呈现周围环境的能力有限，但可以通过提取环境并（部分）将其分配到多声道扬声器系统的周围信道来克服这一限制。附录 I 技术方案中使用基于相关的时频分析综合框架的方法来实现从原始立体声中识别和提取环境信息的功能。

首先计算左右声道的环境估计量：

$$I_A^2 = \frac{1}{2} \left(r_{LL} + r_{RR} - \sqrt{(r_{LL} - r_{RR})^2 + 4|r_{LR}|^2} \right) \dots\dots (I.1)$$

$$\alpha_L = \frac{I_A}{\|\overline{X}_L\|} \quad \alpha_R = \frac{I_A}{\|\overline{X}_R\|} \dots\dots (I.2)$$

式中：

I_A ——环境估计量；

r_{LL} ——左通道自相关信号；

r_{RR} ——右通道自相关信号；

r_{LR} ——左右通道互相关信号；

$\vec{X}_L$ ——左通道信号；

$\vec{X}_R$ ——右通道信号。

信号模型表示为：

$$\begin{aligned}\vec{X}_L &= \rho_L \vec{v} + \vec{A}_L \\ \vec{X}_R &= \rho_R \vec{v} + \vec{A}_R\end{aligned}\quad \dots\dots (I.3)$$

式中：

ρ_L ——左通道复系数；

ρ_R ——右通道复系数；

$\vec{v}$ ——信号向量的线性组合；

$\vec{A}_L$ ——左通道环境估计量；

$\vec{A}_R$ ——右通道环境估计量。

每个通道中的环境估计量可以表示为：

$$\begin{aligned}\vec{A}_L &= (1 - \rho_L c_L) \vec{X}_L - \rho_L c_R \vec{X}_R \\ \vec{A}_R &= -\rho_R c_L \vec{X}_L + (1 - \rho_R c_R) \vec{X}_R\end{aligned}\quad \dots\dots (I.4)$$

式中：

c_L ——左通道线性系数；

c_R ——右通道线性系数。

在相关计算中，自相关和互相关可以用递归公式近似，如式（I.5）所示：

$$\begin{aligned}r_{LL}(t) &= \lambda r_{LL}(t-1) + (1-\lambda) X_L^*(t) X_L(t) \\ r_{RR}(t) &= \lambda r_{RR}(t-1) + (1-\lambda) X_R^*(t) X_R(t) \\ r_{LR}(t) &= \lambda r_{LR}(t-1) + (1-\lambda) X_L^*(t) X_R(t)\end{aligned}\quad \dots\dots (I.5)$$

式中：

λ ——遗忘因子。

由遗忘因子 λ 决定的时间常数 τ 为：

$$\tau = -\frac{1}{f_c \ln(1-\lambda)}\quad \dots\dots (I.6)$$

式中：

f_c ——计算中的采样率。

立体声输入（或不直接涵盖环绕声通道的音源）情况，对信号进行傅里叶变换，假设背

景噪声无关，人声相关性高这一信息，对左右声道进行相关性提取，得到 MASK 值，然后通过时频掩蔽得到对应的环境声信息，再对信号进行逆傅里叶变换，则环绕声信息提取完成，该算法满足设备计算量要求，但是提取效果与立体声音源的制作质量相关，制作越精良，得到的环绕信息效果越好。环境提取（上混）流程如图 I.4。

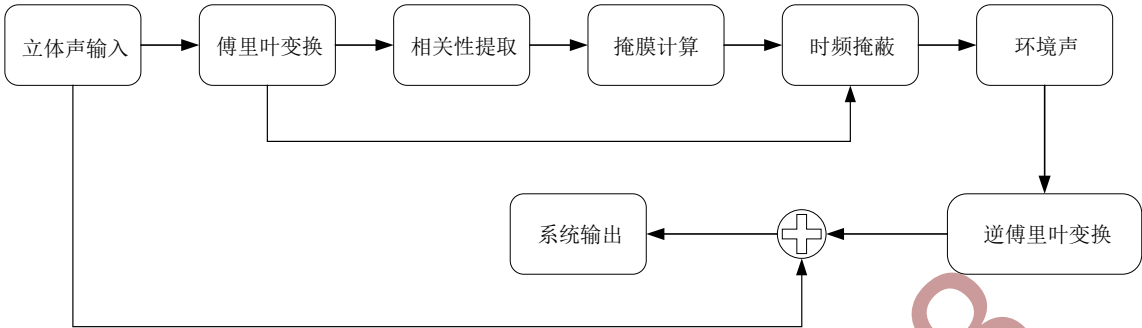


图 I.4 环境声提取流程图

1.2.6 多通道有环绕信号输入

多通道输入音源，大部分自带环绕声信息，例如 ITU-T BS.2051 中 5.1,7.1.2, 7.1.4 等格式，自身包含环绕声信息，通过对应声道信息直接提取环绕声。若出现 7.1.4 等多背景信息的情况，如 4 天空声道，左右 2 个环绕声道，天空声道信息交由解码器处理后在电视端播出，以得到最优的环绕声信息。

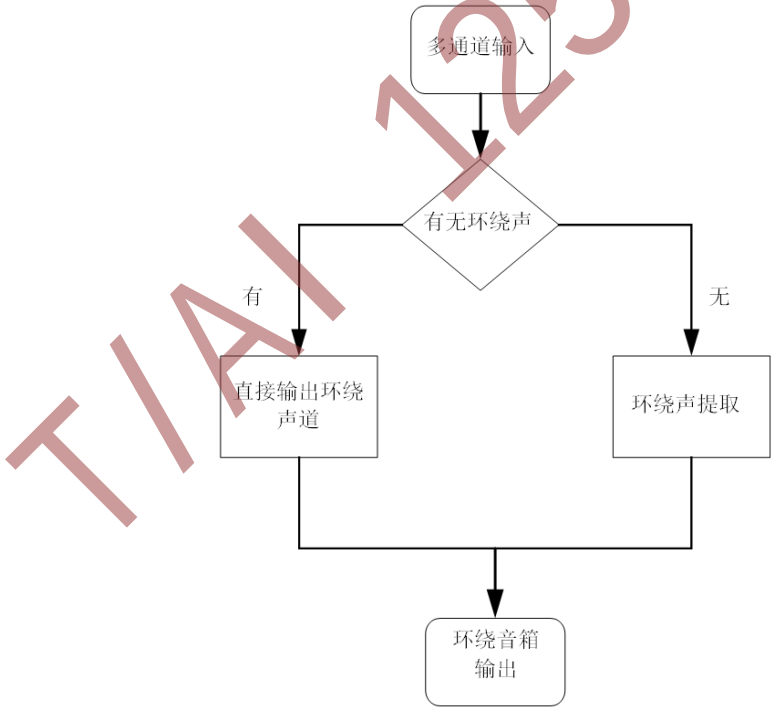


图 I.5 多通道右环绕信号输入时处理流程图

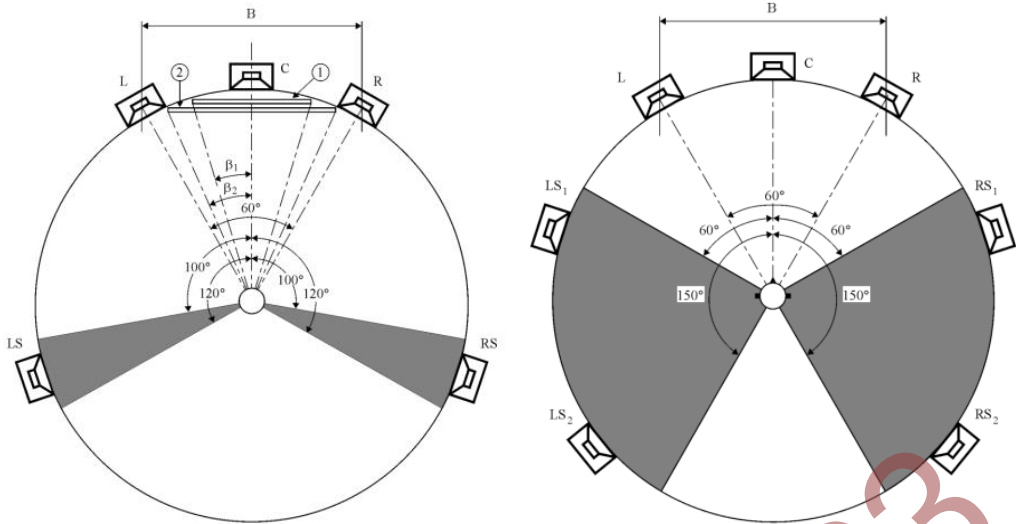


图 1.6 家庭 5.1 布放位置示意图

表 1.5 常见多通道音频输入后环绕声提取方式

常见多通道音频输入后，环绕声提取方式输入音频类型	原始声道输入	环绕音箱直接输出
5.1	LS\RS	左环绕音箱\右环绕音箱
7.1	LS2\RS2	左环绕音箱\右环绕音箱
7.1.2	LS2\RS2	左环绕音箱\右环绕音箱

附录 J
(资料性)
球谐 HRTF 通用制作技术

J.1 概述

附录J为实现双耳渲染的Spherical Harmonic HRTF的个性化制作,以达到任何HRTF库都能在双耳渲染器中使用的目的。

J.2 球谐 HRTF 通用制作技术

一般所说的 HRTF 描述了从声源位置到耳廓时声波的传输过程,通过测量或仿真获取。平面波信号 $s_{\Omega}(\omega)$ 输出双耳信号如下:

$$b_l(\omega) = s_{\Omega}(\omega)H_l(\omega, \Omega) \quad \dots\dots (J.1)$$

式中:

$b_l(\omega)$ ——双耳信号;

$s_{\Omega}(\omega)$ ——平面波信号;

$H_l(\omega, \Omega)$ ——测量或仿真的 HRTF, 其中 $l \in (L, R)$ 。

Ambisonics 到双耳的传统做法是,假定球面上有 N 个虚拟扬声器,先将 Ambisonics 变换到 N 个虚拟扬声器上,这些点位到人耳的 HRTF 是已知的,所以将 N 个扬声器得平面波信号按照 (J.1) 中的方法即可得到双耳音频。这种方法在实际应用上并不完美,主要有以下弊端:

- 1) 卷积计算次数较多,实时性能不高;
- 2) N 是有限的, Ambisonics 变换到虚拟扬声器会损失高频;
- 3) 使用这种方法误差不能最小化。

基于误差最小的思路来实现 Ambisonics 到双耳的渲染过程,是一种更高效的方法。

假设第 N 阶第 j 个 Ambisonic 信号记为 $a_j(\omega) = s_{\Omega}(\omega)Y_j(\Omega)$, 其中 ω 表示频率, $Y_j(\Omega) = Y_n^m(\Omega)$ 表示第 n 阶 m 次球谐函数。双耳渲染需要找到一个渲染滤波器 $\omega(\omega)$, 使得输出信号 $\hat{b}_l(\omega) = \omega_l^H(\omega)\mathbf{a}(\omega)$ 在感知上尽可能接近 $b_l(\omega)$ 。如果将声场建模为来自未知方向的未知平面波信号的叠加,则误差可以写为:

$$\omega^*(\omega) = \arg \min \int_{\Omega \in S^2} D(\omega^H \mathbf{y}(\Omega), H(\omega, \Omega)) d\Omega \quad \dots\dots (J.2)$$

式中:

$\omega^*(\omega)$ ——渲染误差;

$\mathbf{y}(\Omega)$ ——球谐函数;

Ω ——空间方位角,由水平角和俯仰角组成;

ω^H ——渲染滤波器;

$D(\cdot, \cdot)$ ——模拟感知差异的距离函数。

使用最小二乘法将误差函数定义为:

$$\omega_{LS}(\omega^k) = \arg \min \|\mathbf{Y}_M \omega - \mathbf{h}_M\|_2^2 \quad \dots\dots (J.3)$$

式中:

$\omega_{LS}(\omega^k)$ ——渲染误差的最小二乘表示;

M ——头传输函数阶数。

其中 ω^k 是第 k 个分量的中心频率。由于误差函数是一个复变函数，包含幅度项和相位项，基于人耳对于高频相位不敏感原则，设定临界频率 ω_c ，在此频率之上忽略相位带来的差异，将误差函数进一步写为：

$$\omega_{LS}(\omega^k) = \arg \min \begin{cases} \|Y_M \omega - h_M\|_2^2, & \omega \leq \omega_c \\ \| |Y_M \omega| - |h_M| \|_2^2, & \omega > \omega_c \end{cases} \quad \dots\dots (J.4)$$

式中：

ω_c ——滤波器临界频率；

其他与 J.3 保持一致。

根据经验 $\omega_c=2\text{kHz}-3\text{kHz}$ 能够满足大多数场景。求出 (J.4) 中的 ω 即为球谐 HRTF。

J.3 总结

附录 J 是在第 9 章的基础上，为满足个性化 HRTF 定制功能，增加了球谐 HRIR 的定制功能，方便双耳渲染的定制。附录 J 中所使用的技术已在约克大学的 HRTF 库上实现，可以作为验证参考代码的例子。

附录 K (资料性) 采样卷积混响模式

K.1 简介

虚拟现实音频技术中,单声道声音经过 HRTF 滤波后产生左右两个声道,使声音具备方位感。但是 HRIR 是自由场情况下声源到达双耳的脉冲响应,所以不包含周围环境的混响效果,即缺失声场的环境信息。这导致声音经 HRTF 处理后,仅具备方位感而缺乏临场感,而且还依然存在较为严重的“头中效应”,所以引入后期混响处理极为必要。采样卷积混响和人工混响各有优劣。

采样卷积混响是将 HRTF 滤波后的左、右声道数据分别和 IR 序列进行卷积,得到混响处理后的左右双声道数据。采样卷积混响 IR 来自真实声场测试,对声场的重建有更逼真效果。数字系统结构简单固定。附录 K 建议使用采样卷积混响模型,并对其基本参数和指标进行描述。

K.2 基本指标和参数建议

K.2.1 概述

本文件提供一些常见的典型声场的采样卷积混响预设,另外,应支持方便地添加采样卷积混响 IR。附录 K 建议仅定义确定以下最基本的指标和参数。

以下提供一些互联网上可以免费下载到的房间脉冲响应数据库,使用时需要自行评估 licence 相关条款。RIR 分别是:

1) Open AIR Library

- website: <http://www.openairlib.net/>
- data: <http://www.openairlib.net/category/generation-type/real-world>
- doc: <http://www.openairlib.net/category/generation-type/real-world>

该数据库给出了一些声学场所的房间脉冲响应,同时提供了该录音场所的照片,可以大致了解声学场所的大小,形状,房间墙壁材质等信息。

2) C4DM (Center for Digital Music) RIR database (at Queen Mary, University of London)

- website: <http://isophonics.net/content/room-impulse-response-data-set>
- data: <http://isophonics.net/content/room-impulse-response-data-set>
- doc: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5496083

该数据库是在一个英国的一个大礼堂和一个教室中录制的,网页上有场景的照片。

3) MARDY (Multichannel Acoustic Reverberation Database at York) database

- website: <http://www.commsp.ee.ic.ac.uk/~sap/resources/mardy-multichannel-acoustic-reverberation-database-at-york-database/>
- data: <http://www.commsp.ee.ic.ac.uk/~sap/uploads/data/MARDY.rar>
- doc: <http://ehabets.dereverberation.org/files/Wen2006.pdf>

该数据库是英国 imperial college 提供的多通道数据录音,可以随机选取其中一个通道的录音,作为 RIR 使用。

K.2.2 滤波器阶数

采样卷积混响FIR滤波器的阶数。

K.2.3 实现算法

K.2.3.1 直接卷积法

$x(n)$ 直接卷积如式 (K.1)：

$$y(n) = \sum_{i=-\infty}^{\infty} x(i)h(n-i) \quad \dots\dots (K.1)$$

式中：

$x(n)$ ——输入信号；

$h(n)$ ——FIR 滤波器脉冲响应。

这种算法没有组帧带来的延时，当阶数过大时计算量很大。

K.2.3.2 长短序列卷积法

长序列和短序列快速卷积方法如下：

1) 首先介绍两个长度相近的序列的快速卷积方法：

a) 将两个序列分别进行补零使得式 (K.2) 成立：

$$b) \begin{cases} x(n) = \begin{cases} x(n), & 0 \leq n \leq L-1 \\ 0, & L \leq n \leq N-1 \end{cases} \\ h(n) = \begin{cases} x(n), & 0 \leq n \leq M-1 \\ 0, & M \leq n \leq N-1 \end{cases} \\ N \geq M + L - 1 \end{cases} \quad \dots\dots (K.2)$$

c) 式中：

$x(n)$ —— L 点的序列；

$h(n)$ —— M 点的序列。

d) 计算这两个补零后的序列的离散傅里叶变换 $X(k) = \text{DFT}[x(n)]$ $H(k) = \text{DFT}[h(n)]$

e) 计算两个离散傅里叶变化的乘积 $Y(k) = X(k)H(k)$

f) 求解反傅里叶变换得到结果 $y(n) = \text{IDFT}[Y(k)]$

g) 当 N 为 2 的幂时，上述的 DFT 和 IDFT 可以换成快速离散傅里叶变换 FFT（这里不详述 FFT 过程），进一步提高效率。

2) 其次介绍长序列卷积短序列的分段重叠相加法：

当上述过程中 $x(n)$ 若是远远长于 $h(n)$ 时，采用分段卷积，过程如下：令

$$x_i(n) = \begin{cases} x(n), & iL \leq n \leq (i+1)L-1 \\ 0, & \text{其他}n \end{cases}, i=0,1,\dots \quad \dots\dots (K.3)$$

此时

$$x(n) = \sum_{i=0}^{\infty} x_i(n) \quad \dots\dots (K.4)$$

那么

$$y(n) = x(n) * h(n) = \sum_{i=0}^{\infty} x_i(n) * h(n) \quad \dots\dots (K.5)$$

此时每一个 $x_i(n) * h(n)$ 都可以使用 1-5 的过程所述的快速卷积的方法来运算。

这种算法阶数大时计算量有明显优势，但由于需做FFT，组帧延时代价较大。另外，这种从计算量角度的实现方法下，可以和HRTF一起做，即先级联成一个FIR再做快速卷积。

K. 2. 3. 3 两级分段的快速卷积

首先，对 $x(n)$ 进行分段，每个分段的长度为 T ， T 小于滤波器长度 M （组帧带来的延时小于滤波器长度），那么此时：

$$x_i(n) = \begin{cases} x(n), & iT \leq n \leq (i+1)T - 1 \\ 0, & \text{其他}n \end{cases}, i = 0, 1, \dots \quad \dots\dots (K.6)$$

然后计算每段的线性卷积 $x_i(n) * h(n)$ ，使用长短序列分段快速卷积的算法，将每段卷积 $x_i(n) * h(n)$ 视为一个“短序列”和“长序列”的卷积， $x_i(n)$ 是短序列而 $h(n)$ 是长序列。根据 $x_i(n)$ 短序列的长度对 $h(n)$ 进行分段，即将 $h(n)$ 这个长序列分为长度和短序列 $x_i(n)$ 长度相近的段。

$$h_j(n) = \begin{cases} h(n), & jT_1 \leq n \leq (j+1)T_1 - 1 \\ 0, & \text{其他}n \end{cases}, j = 0, 1, \dots \text{且} T_1 \approx T \quad \dots\dots (K.7)$$

宜分成 H 个分段信号序列，然后计算每个 $h_j(n)$ 跟 $x_i(n)$ 的卷积 $x_i(n) * h_j(n)$ ，此时可应用经典的快速卷积方法得到该段的线性卷积结果。然后所有段相加得到总结果 $x_i(n) * h(n)$ ，然后再将每个 $x_i(n) * h(n)$ 相加得到最后的输出结果。对输入信号 $x(n)$ 分段确定了组帧延时 T ， T 大于或等于 32。

总结起来，整个流程如图 K.1：

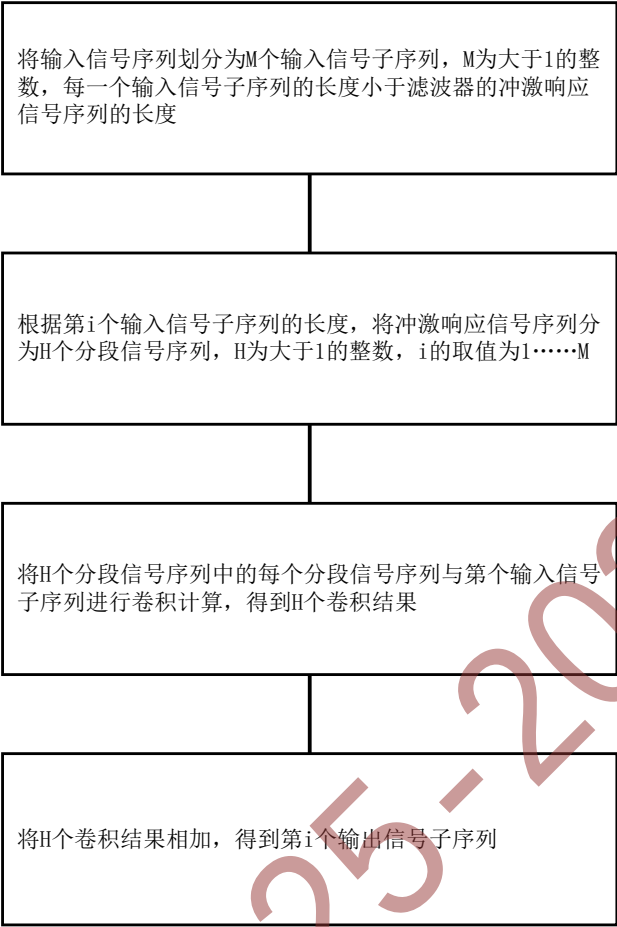


图 K.1 两级分段的快速卷积流程图

- 1) 将输入信号 $x(n)$ 划分为M个信号子序列，每段长度T个样点；
- 2) 计算每段输入 $x_i(n)$ 跟滤波器脉冲响应 $h(n)$ 的卷积，在计算这个卷积时，采用长序列和短序列的快速卷积算法，将 $h(n)$ 视为长序列，将 $x_i(n)$ 视为短序列。再将 $h(n)$ 分成和输入信号子序列 $x_i(n)$ 长度相同或者相近的分段信号序列 $h_j(n)$ ，将每一个分段信号序列 $h_j(n)$ 与输入信号子序列 $x_i(n)$ 进行卷积计算，可以利用快速卷积算法进行卷积计算；
- 3) 将该第i个输入信号子序列分别与每个分段信号序列进行卷积计算之后，获得H个卷积结果，然后利用卷积的性质：卷积的和等于和的卷积，将该H个卷积结果相加，便获得了与该第i个输入信号子序列对应的输出信号子序列，即将该第i个输入信号子序列进行滤波处理完之后的第i个输出信号子序列，即输出结果；
- 4) 过程中所得的 $x_i(n)$ 跟 $h(n)$ 的卷积结果重叠相加得到最终输出。
具体实现算法应可以依据VR音频对实时性以及硬件性能的具体情况进行选择。

K.2.4 处理延时

当实现算法采用直接卷积时，混响处理所带来延时仅来自FIR滤波器的群延时（包络延时）。当采用快速卷积时，混响处理的总延时除了FIR滤波器的群延时外，还有快速卷积的

组帧延时，另外，若混响处理需满足某特定帧长时，一般将涉及帧长适配引入延时。无论采用哪种实现方法，最终的处理延时应精确地给出。

K.2.5 干湿比例

控制干湿声的比例，干声范围0-1（线性增益），湿声范围0-1（线性增益）。一般认为经过混响处理后的都称为湿声，而原声为干声，最终输出由原声和湿声进行线性叠加构成。需要注意的是，叠加前注意将原声延时到跟采样响应第一个能量峰值之处，避免由于湿声延时过大所致的明显的重声现象。一般干湿和为1，那么如果湿声比例为0，则输出的即为原声（未做混响处理的）而湿声比例为1时，相当于没有调整干湿比例，而是直接输出采样卷积混响处理后的声音。一般而言，混响过重的采样卷积混响会使HRTF处理后的方位感模糊，这时宜通过调整干湿比例来减轻混响，从而让混响对方位性的影响变小。

K.2.6 房间脉冲响应

表 K.1 提供了 3 种房间脉冲响应，分别对应小房间，中房间，大房间。

表K.1 房间脉冲响应映射表

hrir_id	采样点数	房间类型
0x0	13800	小房间
0x1	15360	中房间
0x2	15648	大房间

K.2.7 采样卷积混响和 HRTF 的使用方案

采样卷积混响处理是对 3D 化后的左右声道分别进行 FIR 滤波，而滤波器传递函数的时域形式是真实环境测得的脉冲响应。

3D 化后的左右声道经过时域的头相关脉冲响应滤波（HRIR）处理后的音频信号序列与真实环境测得的脉冲响应序列进行卷积计算，得到卷积计算后的左右声道音频信号数据。

$$\begin{cases} hL(n) = \text{hrir_roomL}(n) / 32768.0 \\ hR(n) = \text{hrir_roomR}(n) / 32768.0 \end{cases}$$

$$\begin{cases} yL(n) = xL(n) * hL(n) \\ yR(n) = xR(n) * hR(n) \end{cases}$$

式中：

hrir_roomL ——左声道的采样卷积混响；

hrir_roomR ——右声道的采样卷积混响；

$xL(n)$ ——左声道序列；

$xR(n)$ ——右声道序列。

由于HRTF的时域形式HRIR和采样卷积混响IR在本质上都是脉冲响应，所以使用上可以采用两种方案：

- 1) 将HRTF的时域模式HRIR和采样卷积混响IR先做卷积得到一个更长的FIR滤波器，然后用此滤波器跟输入信号做快速卷积，先集成的好处是可以凑够较长的序列然后便于做快速卷积；
- 2) HRTF和采样卷积混响分开，即先经过HRTF处理再送入采样卷积混响。这样分步骤比较适合运动场景以及多路声音的处理。比如多路声音先经各自不同的HRTF处理，然后混

17,59,67,48,44,21,3,12,38,58,57,51,25,4,-4,-8,-10,10,29,7,-4,-16,4,33,10,-1,-6,7,1,-28,-13,29,35,18,-6,-33,-24,-22,11,38,8,7,8,0,17,32,9,-7,-28,-76,-78,-42,-25,-33,-12,52,89,60,30,19,-5,-30,-37,-10,28,35,6,-3,26,49,44,26,25,15,-19,-32,-3,26,8,-16,-15,12,36,20,-11,-20,-15,-27,-46,-53,-30,-22,-54,-55,-28,-31,-43,-36,-24,-16,-1,-1,-24,-3,4,-28,-36,-51,-10,48,28,-40,-79,-53,1,9,13,71,105,73,30,10,23,60,64,16,-21,-19,-6,-1,10,30,40,10,-38,-51,-35,-1,8,-16,-7,26,55,60,54,38,39,51,23,1,37,74,56,17,-18,-34,-22,-9,2,8,8,-26,-57,-31,6,17,6,-1,-3,11,20,-2,0,0,-13,-1,4,12,-8,-20,-34,-50,-22,12,39,29,-14,-21,5,28,24,-15,-42,-28,-18,-31,-51,-51,-20,-5,-11,-16,-19,-1,3,-18,-27,4,70,109,89,41,13,-7,-23,-4,16,37,38,21,-7,-30,1,15,7,29,24,11,25,26,-14,-55,-28,32,37,5,15,58,74,49,0,-47,-59,-33,-23,-41,-54,-46,-16,-20,-50,-51,-49,-9,44,48,39,23,26,46,51,34,32,19,-22,-43,-40,-24,-11,5,18,6,-19,4,65,71,25,18,37,21,26,34,16,27,37,41,55,20,-49,-52,21,45,23,11,24,43,1,-14,16,43,71,35,50,91,34,-29,-5,108,44,-166,-171,24,181,117,-4,21,68,21,-54,-84,-113,-108,-57,-25,-27,-65,-76,-63,-39,15,55,48,25,10,1,-9,4,49,46,31,27,-1,0,-2,-1,-22,76,143,24,-80,-73,-8,78,98,15,-66,-71,-61,-50,-65,-101,-71,9,86,90,38,-6,-25,-25,-21,-18,-37,-32,2,-13,-28,12,40,12,-27,-34,-15,8,-4,-43,-59,-31,5,-13,-19,14,5,-41,-40,7,51,48,1,-2,8,-35,-89,-86,-15,40,21,-29,-59,-54,2,-54,20,-39,-34,5,43,57,32,-3,-26,-24,-31,-52,-39,3,55,47,1,-19,1,37,-2,-60,-45,8,50,17,-56,-97,-89,-4,56,2,8,-26,-44,-1,22,2,-39,-26,34,39,-10,-37,22,66,43,15,16,34,4,-35,-68,-28,75,55,-60,-98,-5,70,35,-11,0,28,13,-11,-7,-12,-1,33,63,74,18,-52,-45,-5,11,23,24,17,15,6,23,20,-37,-34,69,119,9,-118,-103,-28,-18,-37,-38,-19,10,39,6,6,78,67,20,-24,-11,4,-37,-93,-91,-39,15,24,-22,-52,-24,9,13,7,16,31,14,-1,11,33,20,-15,-19,16,54,54,40,-5,7,64,39,-24,-69,-67,-35,-33,-97,-144,-66,66,117,43,-32,-7,51,76,28,-18,-8,-5,8,21,11,-16,-34,2,19,3,-29,-69,-78,-65,-22,8,-9,-12,-6,-22,-54,-70,-62,-63,-47,-6,30,15,-28,-45,-36,-16,10,36,27,-3,4,25,15,-27,-54,-25,30,49,24,-3,-33,-43,-17,-5,-16,-17,-14,-7,28,50,20,-19,-16,5,17,31,56,30,-56,-50,29,51,43,16,-15,-32,-30,-19,-35,18,4,-97,-84,0,56,44,4,-30,-13,10,42,69,15,14,25,22,55,77,73,20,-23,-52,-27,48,44,-17,-33,16,60,51,36,25,-74,30,57,75,42,-16,-18,-2,1,1,2,25,24,-5,-22,-5,30,19,-7,-26,-6,35,1,-25,-6,5,-10,-26,3,56,59,-13,-62,-51,-3,54,7,-11,45,11,8,-7,-2,-40,-38,35,48,-40,-110,-85,-37,-13,5,2,-17,4,6,-41,-54,-39,-9,7,15,30,10,-34,-37,11,52,79,75,19,-41,-44,-14,-13,-21,-13,-35,-93,-101,-71,-47,-21,-31,-33,19,68,44,-49,-98,-51,-3,-6,-24,-28,-25,-34,-41,-9,57,70,31,10,-7,4,13,2,10,8,-18,-52,-46,-2,9,-32,-57,-49,-24,15,17,-20,-57,-77,-65,-36,-42,-55,-37,-11,12,6,-14,6,41,47,22,-14,-28,-21,-23,10,92,126,108,73,45,31,18,39,63,64,56,8,-59,-71,-27,11,15,-9,-38,-38,0,30,34,24,7,-5,-26,-48,-22,34,64,48,5,-15,-18,-12,11,40,31,6,9,16,24,21,14,33,52,51,23,-13,-11,20,36,10,-1,17,5,-30,-56,-62,-53,-41,-15,-5,-6,5,-10,-22,14,61,45,-1,-20,-12,-1,7,20,19,16,12,28,44,29,-15,-46,-25,-15,-17,-1,9,0,-26,-29,-11,0,11,13,8,-8,-17,-5,-5,-14,-22,-34,-26,-10,-3,-2,3,14,19,-5,-51,-81,-91,-88,-69,-48,-37,-51,-63,-11,66,68,5,-7,39,65,41,2,-16,-6,21,51,6,8,52,43,47,17,-2,8,31,19,-10,-3,-1,-1,5,11,15,-2,-14,-19,-25,-9,4,15,35,35,18,11,12,12,2,-16,-16,-5,3,11,27,30,9,4,17,26,21,-5,-31,-29,1,31,38,21,-1,-11,-16,-13,11,23,17,-1,-6,11,30,29,7,3,32,71,80,56,28,24,46,45,6,-28,-23,-10,-9,-10,3,13,9,7,11,23,41,43,35,25,14,7,24,47,15,-47,-69,-48,-33,-36,-24,-2,-3,-30,-54,-48,2,37,24,-5,-27,-13,11,34,45,28,-2,-14,13,42,44,30,26,29,13,-12,-13,12,24,-4,-35,-26,-6,0,-12,-29,-32,-30,-40,-29,-1,5,2,-1,-6,20,5,9,78,60,20,2,-4,-12,-15,-5,-4,-6,6,6,-22,-28,-7,-2,-16,-23,-3,30,35,5,-27,-19,7,19,13,-1,14,40,29,1,-11,-4,-4,5,-4,-61,-78,-23,31,28,-2,-21,-19,-3,-7,-39,-63,-44,6,33,29,11,5,5,11,17,5,0,5,21,22,13,10,-13,-48,-68,-58,-49,-59,-5,6,-32,-26,-25,-14,-9,2,2,-6,-1,9,10,5,2,4,-4,-16,-9,9,23,26,14,7,-2,-3,17,25,15,19,34,30,14,11,17,22,7,-18,-39,-1,3,4,-15,-37,-24,9,31,17,-30,-53,-42,-23,-1,-2,-9,1,9,9,22,34,43,42,23,-8,-15,16,27,13,13,22,13,16,11,19,27,17,8,5,1,5,-2,-32,-53,-35,-8,1,-16,-56,-79,-64,-31,6,24,24,-1,-31,-23,5,17,2,0,15,26,4,-9,5,21,18,-28,-35,-10,2,-5,-1,5,-13,-6,21,45,64,76,60,28,6,6,21,25,12,-25,-48,-23,-3,-9,-9,13,25,-2,-32,-25,3,35,59,49,2,-40,-47,-39,-22,-10,-18,-27,-4,10,-27,-50,-7,47,42,-1,-41,-61,-53,-23,-8,-27,-43,-24,-2,7,4,1,-5,-14,-16,-15,-9,7,12,-6,-50,-66,-17,37,36,0,-14,-20,-21,-7,5,2,-3,17,30,-4,-66,-50,40,96,81,27,44,38,-90,-157,-68,95,175,124,21,-52,-67,-78,-101,-72,-35,-11,26,23,-22,-37,-16,-16,-56,-62,-4,55,70,49,34,32,81,185,115,-147,-300,-179,85,211,163,79,-2,-56,-60,-3,6,-23,-33,-22,4,30,46,54,48,27,23,34,42,39,26,14,11,11,-5,-23,-48,-68,-61,-48,-36,-21,10,29,10,-9,-7,-11,-36,-5,7,-53,-32,-7,25,44,12,-25,-8,32,43,23,-10,-41,-48,-33,-8,14,7,-8,-10,-10,-12,-3,20,18,0,-13,-18,-7,6,22,16,-7,-1,4,1,26,23,-6,-47,-66,-46,-22,-3,2,-8,-13,-10,-15,-21,-5,9,18,10,3,1,-9,-7,-3,-10,-12,-3,20,42,47,30,12,9,10,17,38,26,-12,-17,9,24,7,-21,-7,30,39,18,-7,-9,2,19,33,27,-1,-25,-29,-18,5,24,1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 1,0,0,0,-1,0,-1,0,-2,-2,-1,1,4,5,3,1,1,0,0,0,-1,0,2,1,0,-2,-2,-2,0,1,2,1,1,2,2,2,1,0,0,0,0,-2,-2,-2,-1,0,-1,0,0,0,0,
 2,2,1,0,-3,-4,-2,2,3,2,0,-2,-2,-1,1,2,3,3,1,2,1,1,0,1,2,2,2,0,0,1,5,5,4,1,-1,-1,0,1,1,0,1,1,3,3,2,1,0,1,1,3,2,2,0,0,-
 1,-1,-1,-1,-2,0,0,1,0,1,0,0,-2,-2,-1,1,1,1,-1,-1,-2,-1,-1,0,-1,-1,0,0,-1,-1,-1,-1,0,-1,-3,-3,-1,0,1,3,4,2,2,1,0,0,0,0,0,
 1,1,1,3,4,4,3,1,-1,-3,-3,-3,-2,-3,-2,-2,-1,-1,0,-1,-1,-2,-1,-2,0,0,-1,-2,-2,0,-1,0,2,2,1,0,1,1,1,2,2,2,1,0,0,-1,0,0,-1,
 -1,-2,-1,0,1,-1,-1,-1,0,0,2,2,1,0,0,0,2,2,3,3,1,0,3,2,3,2,0,0,-1,-1,-1,1,0,1,1,0,2,2,3,3,2,2,0,0,-1,-2,-2,-1,0,-1,-1,0,
 0,0,0,-1,1,2,1,1,1,0,0,1,2,1,1,0,2,2,1,0,-1,-1,0,1,3,5,5,4,2,0,-2,-3,-2,-2,-1,1,0,-1,-2,-2,-1,-1,0,1,0,-1,-1,-2,-2,-1,1,
 2,4,3,2,2,2,1,1,1,1,2,1,-1,-1,-2,-2,-1,1,0,0,0,0,-1,1,2,2,1,2,1,0,-1,-1,-1,1,1,2,2,3,2,1,1,0,0,-1,-2,-2,-1,0,1,1,1,
 1,2,1,2,2,1,1,0,1,0,1,1,0,0,-1,1,-1,0,-1,-1,1,1,2,2,2,2,1,0,-2,-1,0,1,0,1,0,0,0,0,0,-1,0,0,0,0,0,-1,1,1,3,4,3,1,-1,-2,
 -3,0,2,3,2,1,0,0,-1,-2,-3,-2,0,0,1,0,1,0,-1,0,1,2,2,2,1,-1,-2,-2,-1,-1,0,1,1,1,1,0,-1,0,0,1,2,3,3,0,0,-2,-1,-1,-2,-2,-1,
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 1,-1,-1,-1,0,1,0,-2,-3,-4,-4,-4,-3,-3,-2,-1,-1,-2,-1,0,-1,-2,-1,-1,0,-1,-1,-1,-1,-2,-1,-1,-1,0,0,-1,-2,-2,-1,0,0,0,
 1,0,0,0,0,-1,-1,1,2,2,2,2,0,0,1,2,2,2,2,1,1,0,0,0,0,2,2,2,2,1,0,0,0,-1,0,-1,1,2,1,0,-1,0,1,3,3,3,2,1,0,-2,-2,-1,-1,-1,
 1,1,1,1,2,3,2,2,3,1,1,1,1,-1,-2,-1,1,3,3,2,1,0,1,1,1,0,-1,0,0,0,0,-1,-1,0,0,0,-1,-1,-1,0,0,0,-1,0,2,3,3,3,2,1,1,1,0,
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 -1,0,-2,-1,0,1,0,1,1,1,0,1,1,1,0,0,0,1,1,0,-1,-3,-2,-2,0,2,3,2,1,-1,-1,-1,0,1,0,-1,-2,0,0,2,3,3,3,1,-2,-3,-2,-2,-1,-
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 1,0,-1,-1,-2,-1,-1,-1,-2,-3,-2,-1,0,-1,-1,-1,-1,1,0,0,0,1,1,2,1,1,1,0,0,-1,-1,-2,-2,-3,-2,-2,-2,-2,-2,-1,0,1,2,1,1,-
 1,-1,-1,-1,-1,-1,-1,1,0,1,1,0,1,0,-1,0,0,1,0,0,2,3,3,2,2,0,-2,-2,-2,0,1,0,0,-1,-1,-1,-2,-3,-2,-2,0,-1,-1,-1,0,1,0,
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 0,0,0,0,-1,0,-1,-2,-3,-3,-1,-1,-1,-1,1,1,1,1,1,1,1,1,0,2,1,1,1,0,-1,0,-1,-1,-1,1,0,1,0,0,-1,0,1,0,1,1,0,0,-1,-
 1,-1,-1,0,0,1,-1,1,1,0,-1,-1,-1,-1,0,1,2,2,1,0,1,1,0,0,2,1,0,0,0,1,3,3,2,1,0,0,0,-1,1,1,0,0,1,1,1,2,2,1,0,-3,-1,
 -1,-1,0,-1,-1,-1,1,0,0,0,-1,-1,-1,-1,-1,0,1,2,1,1,0,-1,0,1,0,0,0,-1,0,-1,-1,0,-1,-1,0,0,0,-1,-1,-1,-1,0,1,1,1,0,0,-
 1,-1,-1,-2,-1,0,0,1,0,0,1,0,-1,-1,0,0,0,1,1,0,0,-1,0,-2,-1,0,0,1,0,0,1,1,2,2,1,2,0,2,0,0,0,1,0,0,0,-1,-1,-1,0,-1,
 -2,-1,-1,-2,-1,-2,0,0,0,-1,1,2,0,-2,-3,-3,-1,-1,0,1,1,1,1,0,2,1,0,-1,0,1,3,1,1,0,0,1,1,2,2,1,1,1,0,1,1,1,2,1,0,-1,-1,
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 1,1,0,0,-2,-1,0,1,2,3,1,2,1,1,0,0,-1,-1,-2,-1,1,0,1,1,1,0,-1,-1,0,0,0,0,1,2,2,1,1,1,1,0,1,0,0,0,0,-1,0,-1,-1,0,0,1,-1,
 0,1,2,2,3,2,1,-1,-1,-1,0,0,0,1,3,2,2,1,1,1,0,1,1,2,2,0,-1,-1,0,1,1,2,2,1,3,3,3,2,2,2,0,0,0,1,2,2,1,0,0,1,1,1,0,0,0,0,-
 2,-2,-1,0,1,1,2,1,0,-1,1,0,2,2,2,2,3,2,2,0,0,0,-2,-1,0,1,2,2,2,1,1,0,1,0,0,0,0,1,2,1,1,0,0,0,-1,0,0,0,0,-1,-1,0,-1,-1,
 0,1,1,1,-1,-2,-2,-1,1,1,1,1,0,-1,-1,-1,-1,0,1,0,-1,-1,-2,-1,0,0,0,0,0,-1,1,0,1,1,0,1,0,2,2,1,0,0,0,1,1,0,0,-1,-2,-2,-1,0,
 0,1,0,0,0,-1,-1,-1,0,0,1,1,1,2,0,0,0,1,1,2,1,2,1,0,-1,-1,-1,-1,-1,0,1,0,0,-2,-3,-3,-2,-2,0,2,2,2,2,1,1,-1,-1,0,0,0,1,1,-
 1,-1,-1,-1,0,1,2,1,0,0,-2,-1,-1,-2,-3,-3,-2,-1,-1,0,0,0,0,1,0,-1,-2,-2,-2,-1,-1,0,0,0,0,1,0,-1,-2,-2,-1,0,1,1,0,-1,-2,-2,-1,-1,
 0,0,0,0,-1,0,0,1,0,1,-1,-2,-1,-1,-1,-1,0,0,0,-1,0,0,0,0,-1,-1,-2,-1,0,0,0,0,0,-1,0,-1,0,1,1,1,0,1,0,0,-1,-2,-2,-2,-2,
 -2,-1,0,0,1,1,0,0,-2,-1,0,0,0,0,-1,1,1,3,2,2,0,-2,-1,0,1,1,0,-1,-1,0,0,1,1,0,1,0,1,1,0,0,-1,-1,0,0,-1,-1,-2,-2,0,1,1,0,
 0,-1,0,1,1,1,0,0,0,-1,-3,-3,-2,-1,-1,0,0,1,1,2,1,2,1,-1,0,-1,-1,1,2,2,0,0,-1,0,0,0,1,1,1,2,2,1,0,-1,1,0,1,1,1,0,-1,
 0,1,0,0,1,0,0,-2,-1,-1,0,0,0,0,0,1,0,1,1,0,0,-1,-1,0,1,0,0,-1,-1,-1,-1,-1,-2,-1,-2,-3,-2,-2,-1,0,-1,-1,-1,0,-1,-1,
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 2,-1,-1,0,0,0,0,0,1,1,1,-1,-1,-1,0,1,1,1,0,0,0,1,2,1,3,2,2,1,1,0,0,0,-1,-1,-1,-1,-1,-2,-3,-2,-1,-1,1,1,1,0,0,-1,0,-1,-1,
 1,1,-1,0,-1,-1,0,0,0,0,-1,-1,1,0,-1,-1,0,0,0,-1,-1,0,0,0,0,-1,0,1,0,-1,0,0,0,0,1,1,1,1,0,1,1,1,-1,-1,-1,-1,0,-1,0,
 0,-1,-1,0,0,0,-1,-1,-1,0,0,1,1,1,0,0,-1,-1,-1,-1,-1,-2,-1,-1,0,1,1,1,0,0,-1,-1,0,0,0,0,0,0,1,0,1,0,0,0,-1,1,1,
 -1,-1,0,0,-1,-1,-1,-1,0,1,2,2,2,0,0,1,0,0,0,-1,0,0,1,1,0,0,0,0,0,1,0,1,1,0,0,0,0,0,1,0,1,1,0,-1,-1,-1,-1,-1,-1,
 0,1,0,-2,-2,-2,-1,-1,0,0,0,0,0,0,0,-1,-1,-1,-1,0,0,0,0,0,1,0,0,0,0,1,1,1,1,-1,0,0,0,0,-1,0,-1,-2,-1,-1,0,0,0,1,0,0,
 -1,-1,-1,0,0,0,-1,-1,0,0,1,0,0,1,0,0,-1,-1,-1,0,-1,1,1,2,1,1,-1,-1,-1,0,0,0,0,-1,0,0,0,0,-1,-1,-1,0,0,0,2,1,1,0,1,1,
 0,0,0,1,1,1,1,1,0,0,0,-1,1,0,1,2,2,2,0,0,0,-1,1,0,0,0,0,0,0,0,0,1,1,2,1,1,2,2,2,0,0,0,-1,0,-1,-1,-1,0,0,


```
0,0,1,1,1,2,3,2,2,2,3,2,3,2,1,1,1,1,0,1,0,1,0,0,-1,-1,-1,-1,-1,-1,-1,-1,-1,0,0,1,2,2,2,1,1,-1,0,0,1,0,1,0,1,0,1,1,0,
0,0,1,0,-1,-1,-1,0,0,0,1,1,0,0,0,0,1,0,0,-1,-1,0,0,0,0,-1,0,1,0,0,0,0,-1,0,0,0,1,1,1,0,0,0,0,1,1,1,1,0,0,-1,0,0,0,
0,0,1,1,2,3,2,3,2,2,2,1,2,1,2,1,2,1,0,0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,0,1,1,1,1,-1,-1,-2,-2,-1,0,1,0,-1,0,-1,0,-
1,-1,0,1,0,1,0,1,1,0,0,-1,0,0,0,0,0,-1,-1,-1,-2,-1,0,0,-1,1,1,0,0,1,1,1,0,1,0,-1,-1,-1,-1,-1,-1,0,1,1,0,1,-1,1,
0,1,1,-1,0,-1,-1,1,1,0,0,1,1,1,1,0,0,-1,0,0,0,-1,0,0,0,-1,-1,-1,0,0,0,1,0,0,-1,-1,-2,-1,-1,0,0,1,0,0,-1,-3,-3,-1,0,0,1,
0,0,-1,-1,0,-1,0,1,1,1,1,1,2,1,1,0,0,1,1,2,2,2,1,0,0,0,-1,0,0,0,-1,0,0,0,0,-2,-1,-1,-2,-1,0,0,};
```

采样卷积混响可适当调节干湿比例，适当调整混响长度，例如当性能受限时，可采用前9000点而舍去后面的点。使用时用hrir_roomL、hrir_room1R经归一化转换为float型数据，跟HRTF处理后的左、右声道分别做卷积得到加混响后的最终输出。

附录 L

(资料性)

一种空间音频距离衰减模型

L.1 概述

附录 L 提出一种针对空间音频距离衰减模型的实现方法。

L.2 方案描述

L.2.1 概述

人类对声源与自身的距离的估计是一个非常复杂的过程。从建模来考虑,这个距离估计包含了相当多的参数。其中一种方法为使用包含了距离参数的 HRTF 数据库来进行空间音效重建,但这种方法依赖于特定的 HRTF,目前仍然不是一种主流的方法。附录 L 探讨的一种声音空气衰减模型基于数字信号处理理论,针对声音在空气传播时,对应于不同距离人耳所能感知的不同参数进行建模:

- 1) 当音源跟听众之间的距离处于近场范围时,对声音做近场效应处理;
- 2) 当音源跟听众之间的距离处与中距范围时(此处根据经验,推荐值为2米至15米),对声音做能量全局衰减;
- 3) 当音源跟听众之间的距离为远距范围是(此处根据经验,推荐值为大于15米的距离),对声音做能量衰减,同时做频率衰减。

L.2.2 全局衰减模型

假设声源和听众之间的距离为 d , 那么全局衰减可以为 $A(d)$

$$A(d) = \alpha * \log_{10} \left(\frac{d_{ref}}{d} \right) \quad \dots\dots (L.1)$$

式中:

α ——可配置衰减因子,默认值为 1;

d_{ref} ——测量 HRTF 时的距离。

随着声源和听众之间的距离发生变化,有必要引入平滑因子以避免衰减值突变导致的 Pop 噪声。平滑因子使用一阶低通滤波器来实现

$$a_i = (1 - \rho) * a_{i-1} + \rho * A(d) \quad \dots\dots (L.2)$$

平滑控制因子 ρ 由响应时间 t_a 决定, t_a 这里为 100ms:

$$\rho = 1 - \exp \left(\frac{\log(0.01)}{t_a * f_s} \right) \quad \dots\dots (L.3)$$

式中:

f_s ——信号的采样率。

L. 2.3 频率选择性衰落

当声源大于 15 米时，需要考虑空气对声音不同频率的衰减特性，参考 ISO 9613-1。假设温度为 25 摄氏度，湿度为 50%时，声源距离 100 米处空气对声音的衰减曲线如图 L.1 所示：

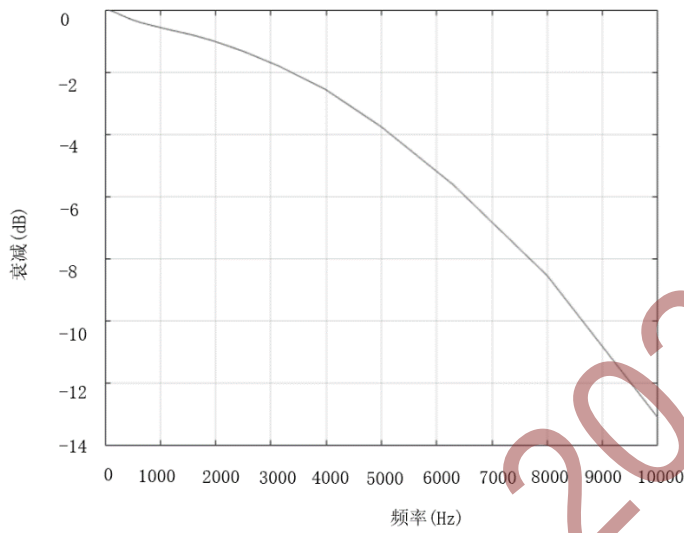


图 L.1 声源距离 100 米处空气对声音的衰减曲线

对声音在 100 米距离传播时不同频率的声音衰减特性，使用一个级联滤波器来逼近这个衰减曲线。

该滤波器系数如下：

$b_0=0.767020$, $b_1=1.534039$, $b_2=0.767020$, $a_0=1$, $a_1=1.394837$, $a_2=0.673242$

附录 M
(资料性)
一种三维声近场效应实现方法

M.1 概述

附录 M 提出一种针对三维声双耳渲染场景的近场效应实现方法。

M.2 方案描述

附录 M 提出了一种模拟近场音源的方法,即使用“差异化滤波器”来补偿近场与远场之间的频谱差异。此外,还针对位置信息对延迟和增益的模拟提出了解决方案。

当前大部分 HRTF 库是距离头部固定距离的远场上进行测量,这就意味着,这些 HRTF 库不适于重现近场音源的渲染重放。一个解决办法就是在不同的距离上测量 HRTF 参数,这样测量得出的 HRTF 库能满足不同距离音源的渲染需求,但带来的问题是 HRTF 库的测量需要的工作量急剧增加。针对这种困境,附录 M 提出一种近距效应补偿方法,实现框图如图 M.1 所示:

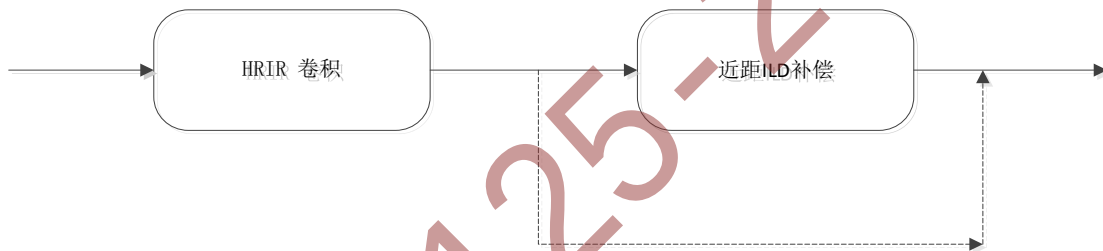


图 M.1 近距补偿示意图

对于近距的距离,可以根据所使用 HRTF 库测量时的距离 d 来作为门限,也可以根据音频的有效最长波长 λ (取决于音频系统的最低有效频率) 来进行计算: $d < \lambda$ 。例如,对于常用的通信系统,音频的最低截至频率为 300Hz, 300Hz 对应于的最长波长为 1.13 米。所以对于该音频系统,其近距 d 为 1.13 米。

当音源距离大于或者等于 d 时,不做近距 ILD 补偿,反之,当音源距离小于 d 一定距离时,音频经过 HRIR 卷积后,使用矫正滤波器对音频做进一步的 ILD 补偿处理。其中矫正滤波器可以通过下列公式获得:

$$Filter_{diff} = ILD_{near-field} / ILD_{far-field} \quad \dots\dots (M.1)$$

其中 $ILD_{near-field}$ 由 $HRTF_{near-field}$ 来进行计算, $HRTF_{near-field}$ 的计算为将头部近似为圆球模型,根据 Duda 等利用圆球对点声源产生的球面波的散射公式,得到了圆球模型的 HRTF 解析公式

$$H_L(r, \theta, f) = -\frac{r \exp(jkr)}{ka^2} \sum_{l=0}^{\infty} \frac{(2l+1) h_l(kr) p_l(-\sin\theta)}{dh_l(ka)/d(ka)} \quad \dots\dots (M.2)$$

式中:

a ——球半径;

$k = 2\pi f/c$ ——波数;

$P_l(-\sin\theta)$ ——1 阶勒让德多项式;

$h_l(kr)$ ——1 阶第二类球 Hankel 函数。

使用此公式，可以计算出 $HRTF_{near-field}$ 在某个点位的具体值，进而可以得到该点位的 $ILD_{near-field}$ 。

为了节省计算资源，可以提前计算 $ILD_{near-field}$ 以及 $Filter_{diff}$ ，并将计算出来的 $Filter_{diff}$ 存在表格里。使用的时候，根据坐标查找所需要的 $Filter_{diff}$ 。滤波器为两个直接 II 型 IIR 滤波器级联而成。其结构图如图 M.2 所示：

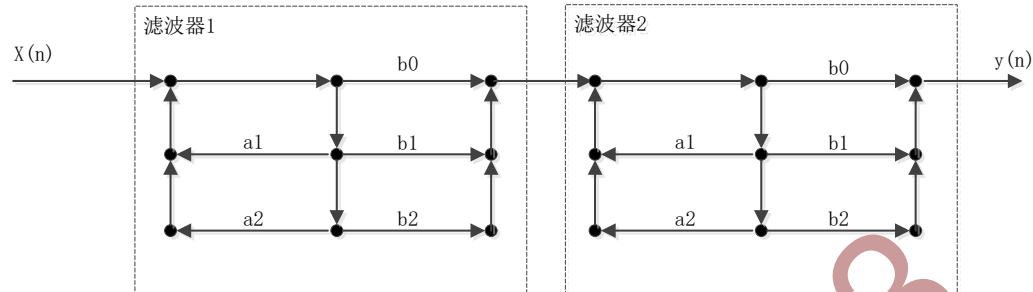


图 M.2 差异化滤波器结构图

滤波器系数见表 M.1。

表 M.1 滤波器系数

距离（步长 10 厘米）	角度（精度为 5 度）	滤波器 1 的系数（b0,b1,b2,a1,a2）					滤波器 2 的系数（b0,b1,b2,a1,a2）				
100 85	0.229573	-0.285960	0.084936	-1.380765	0.467477	0.789683	-0.722207	-0.019154	-1.220210	0.263059	
1070 30	0.932948	-0.819746	0.113395	-0.898770	0.132733	1.000102	-1.834946	0.867690	-1.834537	0.867314	
1670 55	0.984989	-0.725362	0.088948	-0.739814	0.091748	0.999900	-1.722128	0.800847	-1.722301	0.800890	
1560 -85	1.012366	-1.508699	0.541505	-1.490150	0.534778	0.999463	-1.906606	0.910289	-1.907875	0.911007	
1160 -50	1.022168	-1.278791	0.301302	-1.250346	0.293667	0.999706	-1.915403	0.920636	-1.916078	0.921002	
120 75	0.289755	-0.340667	0.092570	-1.320356	0.423486	0.868022	-0.716049	-0.016059	-1.012672	0.138344	
130 -35	0.831571	-0.772132	0.127045	-1.024857	0.206434	0.972223	-1.813482	0.847254	-1.878763	0.883825	
100 -50	1.014830	-0.812117	0.097556	-0.915081	0.151147	0.959858	-1.794592	0.839595	-1.889711	0.893556	
140 -10	0.482962	-0.379735	0.030160	-1.035186	0.209149	0.988960	-1.818363	0.840984	-1.842714	0.853239	
100 25	0.187428	-0.120438	-0.001498	-1.137618	0.278770	1.009741	-1.816951	0.844335	-1.792420	0.829171	
1760 40	0.990533	-0.792900	0.099302	-0.802961	0.101427	0.999964	-1.803167	0.845162	-1.803222	0.845167	
750 -70	1.078287	-1.155100	0.292832	-1.069514	0.270606	0.996013	-1.905298	0.911869	-1.914800	0.917305	
160 -40	1.076390	-0.967398	0.164528	-0.916880	0.156636	0.970126	-1.822428	0.856447	-1.893467	0.896964	
110 -25	0.499773	-0.387756	0.033121	-1.032841	0.214251	0.973798	-1.806255	0.839877	-1.867357	0.873692	
200 15	0.498269	-0.409102	0.036815	-1.036668	0.203599	1.004793	-1.834725	0.855291	-1.822140	0.847095	
130 10	0.322940	-0.242309	0.011636	-1.102801	0.248455	1.007175	-1.832599	0.848335	-1.813825	0.836159	
710 5	0.903446	-0.867699	0.127194	-0.995883	0.162989	1.001530	-1.843224	0.861516	-1.839316	0.859055	
100 -70	2.583375	-0.933749	-0.489893	-0.367880	-0.195737	0.943183	-1.769740	0.829833	-1.905666	0.908060	
750 25	0.877436	-0.787211	0.108570	-0.936756	0.146890	1.000523	-1.841844	0.871373	-1.840325	0.870270	
560 -15	0.947389	-1.029905	0.209177	-1.108255	0.233307	1.001485	-1.855186	0.865790	-1.851247	0.863195	
740 -5	0.937524	-0.942946	0.156328	-1.029108	0.181069	1.001283	-1.846124	0.859981	-1.842789	0.857836	
1230 70	0.945683	-1.147570	0.259991	-1.227631	0.287833	1.002564	-1.036419	0.376620	-1.030586	0.373519	
1190 10	0.959953	-0.929896	0.140584	-0.982746	0.155331	1.000541	-1.846119	0.868164	-1.844741	0.867301	
160 -60	1.550104	-1.824375	0.377081	-1.173729	0.228274	0.999209	-1.927204	0.934022	-1.928839	0.934744	

100 -90 8.170295 -10.178767 2.954295 -1.248599 0.356916 0.943090 -1.754895 0.817236 -1.889408 0.893254
 180 5 0.495250 -0.404025 0.034297 -1.046106 0.208745 1.003432 -1.832865 0.848520 -1.823120 0.841602
 1160 -90 1.034736 -1.368657 0.441447 -1.322308 0.426343 0.998361 -1.911023 0.915247 -1.914924 0.917474
 120 -80 3.215676 -4.017397 1.255982 -1.240443 0.379655 0.954276 -1.779904 0.830984 -1.887804 0.891812
 120 35 0.253818 -0.174629 0.005676 -1.056482 0.225598 1.007135 -1.798291 0.839445 -1.780033 0.827925
 1560 -45 1.007258 -1.165265 0.220063 -1.156457 0.218012 0.999615 -1.890734 0.895644 -1.891634 0.896144
 660 80 0.839584 -0.571643 0.066289 -0.715574 0.094412 0.997974 -1.664470 0.697632 -1.669195 0.700247
 110 -5 0.308303 -0.216316 0.006371 -1.095699 0.252334 0.991343 -1.812473 0.834929 -1.830676 0.843266
 100 -65 1.962563 -1.274472 -0.061381 -0.681780 -0.029662 0.959828 -1.765701 0.814180 -1.858596 0.864903
 180 -25 0.817996 -0.793454 0.134744 -1.050243 0.211505 0.986981 -1.835225 0.856240 -1.865034 0.872254
 1700 15 0.989713 -0.951121 0.143952 -0.964481 0.147627 1.000104 -1.849422 0.874405 -1.849154 0.874233
 710 -5 0.932988 -0.936007 0.154334 -1.028293 0.180806 1.001334 -1.846134 0.859903 -1.842657 0.857659
 160 -35 0.942363 -1.088285 0.264876 -1.207546 0.312117 0.992713 -1.850980 0.866364 -1.866987 0.874361
 150 -10 0.521693 -0.420923 0.037342 -1.030142 0.204220 0.989826 -1.821218 0.842862 -1.843632 0.854117
 1200 -25 1.001758 -0.681156 -0.081164 -0.680790 -0.081457 0.999142 -1.870913 0.878684 -1.872867 0.879722
 1190 -60 1.026857 -0.518283 -0.009155 -0.503576 -0.009149 0.998428 -1.913480 0.917446 -1.917231 0.919597
 160 10 0.417949 -0.329947 0.023643 -1.064699 0.222112 1.006022 -1.830797 0.847347 -1.814893 0.836917
 130 -40 0.956550 -0.986153 0.202960 -1.095961 0.248595 0.974313 -1.820217 0.851839 -1.880456 0.885473
 100 -85 6.827728 -3.463645 -1.233217 -0.506329 -0.191158 0.933891 -1.741953 0.812278 -1.899468 0.902383
 100 40 0.181842 -0.115569 -0.000840 -1.106682 0.261937 1.006498 -1.789710 0.842742 -1.773277 0.832526
 140 -25 0.681301 -0.594688 0.077845 -1.017237 0.197946 0.979055 -1.818663 0.847108 -1.867308 0.873856
 1760 25 0.991320 -0.911743 0.134602 -0.922414 0.137364 1.000034 -1.845578 0.875183 -1.845477 0.875109
 570 50 0.805384 -0.604282 0.067335 -0.800992 0.106721 0.999354 -1.759564 0.824681 -1.760418 0.824583
 200 30 0.468542 -0.367898 0.032220 -0.992217 0.184309 1.003680 -1.817694 0.852128 -1.807777 0.845471
 110 -10 0.341029 -0.243102 0.009559 -1.080122 0.243089 0.986115 -1.809704 0.835350 -1.840554 0.851085
 520 35 0.787512 -0.646124 0.077499 -0.884941 0.132114 1.000065 -1.816376 0.854422 -1.815634 0.853494
 560 55 0.800763 -0.631442 0.079786 -0.838374 0.124581 0.999026 -1.741736 0.819988 -1.743418 0.820404
 170 15 0.428120 -0.340832 0.026184 -1.055756 0.216561 1.006216 -1.832036 0.851937 -1.815926 0.841609
 110 45 0.218121 -0.156048 0.005415 -1.112052 0.263695 1.001578 -1.818371 0.877042 -1.813815 0.873754
 560 -20 0.969530 -1.216884 0.326172 -1.269450 0.345335 1.002368 -1.873508 0.884242 -1.867703 0.880781
 1130 -70 1.034208 -0.940013 0.186885 -0.908136 0.180375 0.998244 -1.911866 0.916134 -1.916049 0.918527
 160 -55 1.413408 -1.558770 0.263547 -1.102760 0.171722 1.001713 -1.904971 0.910792 -1.900385 0.907735
 160 -90 2.185044 -2.913438 0.896936 -1.326571 0.404196 0.965863 -1.818608 0.856770 -1.899628 0.902845
 210 20 0.504842 -0.413010 0.038440 -1.021952 0.196667 1.004213 -1.831710 0.856242 -1.820585 0.848948
 1190 40 0.945290 -0.753430 0.092547 -0.811664 0.104871 0.999813 -1.801856 0.844406 -1.802122 0.844404
 1130 -75 1.034747 -1.528316 0.524372 -1.476730 0.506397 0.998929 -1.904676 0.909300 -1.907194 0.910712
 100 -60 1.564303 -1.489606 0.308098 -0.999798 0.219708 0.951962 -1.783743 0.835768 -1.898187 0.901224
 560 60 0.800585 -0.643028 0.083784 -0.851558 0.130190 0.998754 -1.698893 0.797325 -1.701231 0.798121
 180 -40 1.101388 -0.775979 -0.028095 -0.713151 -0.030294 0.977756 -1.833842 0.861253 -1.886260 0.890739
 1700 40 0.987127 -0.789930 0.098790 -0.803614 0.101680 0.999951 -1.803067 0.845107 -1.803142 0.845113
 110 -35 0.678335 -0.574905 0.070764 -1.022270 0.203686 0.972253 -1.811603 0.845757 -1.876593 0.881974
 1120 -60 1.031234 -0.596712 0.027841 -0.577348 0.026678 0.998171 -1.912685 0.916918 -1.917050 0.919421
 200 85 0.462864 -0.309901 0.024287 -0.833914 0.134523 0.990898 -1.610622 0.656388 -1.631240 0.667266
 100 35 0.182718 -0.113840 -0.001464 -1.103142 0.258774 1.008521 -1.793870 0.835098 -1.772324 0.821709

250 60 0.547718 -0.468770 0.056117 -0.988770 0.185955 0.996017 -1.729612 0.809359 -1.738496 0.813922
 130 80 0.331017 -0.415027 0.124189 -1.349843 0.443988 0.857001 -0.848164 0.025637 -1.189421 0.221312
 100 -80 4.729448 -6.141921 1.868898 -1.304420 0.392156 0.957478 -1.783000 0.831570 -1.882734 0.887267
 1610 15 0.985240 -0.945733 0.142718 -0.964893 0.147986 1.000149 -1.849341 0.874277 -1.848957 0.874031
 1550 5 0.985899 -0.975872 0.153525 -0.994831 0.158876 1.000258 -1.844278 0.864242 -1.843627 0.863839
 160 65 0.376275 -0.333052 0.030298 -1.100022 0.238117 0.979199 -1.513891 0.632904 -1.559774 0.656000
 160 -85 2.133480 -2.952405 0.924643 -1.383118 0.429219 0.978695 -1.847076 0.872787 -1.897321 0.901085
 560 -50 1.083585 -1.319227 0.287737 -1.214250 0.261248 0.997542 -1.898730 0.905549 -1.904496 0.908770
 1190 -90 1.032544 -0.971932 0.179438 -0.940873 0.173614 0.998457 -1.915005 0.918896 -1.918685 0.921004
 160 40 0.370235 -0.273325 0.018694 -0.990736 0.186960 1.004083 -1.793558 0.844042 -1.782644 0.836782
 200 -25 0.858529 -0.870218 0.162649 -1.077064 0.226474 0.990361 -1.841474 0.859474 -1.863246 0.870905
 110 15 0.237196 -0.164035 0.002545 -1.130728 0.270687 1.008921 -1.826121 0.844275 -1.803171 0.829695
 100 10 0.206548 -0.137296 -0.001451 -1.167779 0.297505 1.008895 -1.832328 0.846959 -1.809302 0.832218
 170 45 0.394381 -0.300717 0.024248 -0.990607 0.188317 1.001814 -1.798502 0.857912 -1.793153 0.853974
 130 -70 2.177644 -2.511796 0.527554 -1.148825 0.227922 0.982069 -1.843585 0.867237 -1.885214 0.890115
 100 -55 1.216796 -1.284241 0.248905 -1.149676 0.261674 0.983542 -1.834635 0.858330 -1.872062 0.878210
 1780 45 0.991518 -0.748107 0.086026 -0.756619 0.087678 0.999951 -1.780663 0.830686 -1.780747 0.830707
 1070 5 0.954809 -0.934436 0.143206 -0.994897 0.160197 1.000785 -1.844001 0.863279 -1.842013 0.862041
 100 -75 3.464498 -3.397771 0.774680 -0.975635 0.213160 0.941685 -1.762185 0.824418 -1.901238 0.904056
 1130 -30 1.006116 -0.958166 0.074441 -0.953043 0.073222 1.000452 -1.869066 0.877712 -1.867893 0.876959
 100 -45 0.831733 -0.750452 0.108664 -1.056889 0.225257 0.964708 -1.801830 0.842451 -1.885172 0.889487
 710 -25 1.002205 -0.587233 -0.111334 -0.588605 -0.112049 0.996458 -1.871129 0.880529 -1.879387 0.885096
 140 20 0.332228 -0.248907 0.013889 -1.071484 0.229977 1.007029 -1.826224 0.849370 -1.808038 0.837734
 110 5 0.262216 -0.183035 0.003437 -1.128475 0.269942 1.004558 -1.826261 0.841467 -1.813165 0.832060
 1220 70 0.944511 -1.145470 0.259351 -1.227235 0.287780 1.002626 -1.036270 0.376277 -1.030297 0.373103
 160 -15 0.614195 -0.517728 0.057157 -1.013866 0.193847 0.986860 -1.823078 0.845996 -1.852824 0.861674
 180 -5 0.567274 -0.471082 0.045687 -1.024177 0.196756 0.996192 -1.828492 0.845851 -1.835849 0.848589
 560 -60 1.104508 -1.505976 0.442867 -1.362088 0.398414 0.998631 -1.910891 0.916789 -1.914065 0.918529
 100 0 0.235396 -0.157693 -0.000549 -1.152045 0.289036 0.999832 -1.822977 0.839977 -1.820985 0.836788
 230 65 0.518091 -0.456018 0.053107 -1.022115 0.198881 0.991279 -1.581243 0.695384 -1.600311 0.704826
 110 30 0.221341 -0.148065 0.002282 -1.092033 0.248070 1.008413 -1.805618 0.838935 -1.784249 0.825578
 750 -40 1.034336 -1.164957 0.191214 -1.125305 0.182228 1.000046 -1.942092 0.949573 -1.941944 0.949456
 520 80 0.782121 -0.541342 0.061351 -0.741646 0.101183 0.997734 -1.676140 0.709617 -1.681408 0.712518
 170 60 0.395629 -0.333706 0.032343 -1.054059 0.219876 0.994234 -1.732166 0.801562 -1.745729 0.809169
 160 25 0.381738 -0.292401 0.020505 -1.037995 0.209762 1.005618 -1.821328 0.849701 -1.806657 0.840208
 200 -10 0.664442 -0.579714 0.068531 -1.015409 0.188929 0.994569 -1.833223 0.850339 -1.844685 0.855629
 100 -40 0.694152 -0.555510 0.061876 -0.993289 0.196916 0.961544 -1.795310 0.838750 -1.886471 0.890497
 1060 45 0.927916 -0.700471 0.079305 -0.773356 0.093624 0.999653 -1.779415 0.830556 -1.779976 0.830649
 1200 15 0.956570 -0.913302 0.135807 -0.969617 0.151290 1.000438 -1.849631 0.874391 -1.848500 0.873670
 130 -85 2.918555 -3.840560 1.074794 -1.320171 0.364518 0.978433 -1.852038 0.877448 -1.903260 0.906610
 130 40 0.284915 -0.204782 0.010072 -1.043079 0.217205 1.005003 -1.797590 0.850212 -1.784721 0.842036
 140 15 0.342358 -0.258877 0.014428 -1.080870 0.234577 1.007656 -1.827129 0.845874 -1.807358 0.833254
 160 -70 1.877719 -2.291047 0.589634 -1.203718 0.300369 0.964072 -1.819675 0.858885 -1.905420 0.908056

1130 -55 1.026566 -1.354157 0.364435 -1.318499 0.354040 0.999623 -1.923838 0.928557 -1.924718 0.929047
 120 -5 0.355171 -0.260959 0.012232 -1.080753 0.239365 0.993433 -1.818195 0.838676 -1.831548 0.844350
 520 -10 0.915099 -0.930983 0.160717 -1.049994 0.195417 1.001355 -1.850250 0.862001 -1.846544 0.859473
 110 35 0.219070 -0.147448 0.002569 -1.088141 0.245547 1.008121 -1.796285 0.840526 -1.776084 0.828241
 700 -20 0.981311 -1.292275 0.375919 -1.326021 0.389040 1.001283 -1.887050 0.899518 -1.883921 0.897666
 760 -50 1.051801 -1.298402 0.293740 -1.232649 0.276645 0.998974 -1.910179 0.915754 -1.912575 0.917083
 1740 25 0.990300 -0.910613 0.134361 -0.922537 0.137446 1.000038 -1.845547 0.875153 -1.845434 0.875070
 620 -60 1.089456 -1.492021 0.441980 -1.368302 0.403506 0.998789 -1.913260 0.918878 -1.916076 0.920429
 110 -80 3.679401 -4.479142 1.153877 -1.238896 0.311326 0.998810 -1.862155 0.871565 -1.862963 0.870292
 200 80 0.494123 -0.534067 0.131049 -1.153593 0.310489 0.928171 -0.950815 0.057049 -1.122418 0.155607
 570 60 0.804940 -0.645604 0.084159 -0.849227 0.129378 0.998783 -1.698104 0.796753 -1.700379 0.797520
 1110 -70 1.035721 -0.944087 0.188646 -0.910708 0.181795 0.998167 -1.911650 0.915997 -1.916018 0.918496
 210 45 0.479739 -0.367792 0.033375 -0.945488 0.165015 1.001277 -1.791600 0.849642 -1.787445 0.846313
 100 70 0.202890 -0.161359 -0.004034 -1.150888 0.262733 0.893402 -1.133278 0.372225 -1.356864 0.474088
 240 60 0.532368 -0.456873 0.054110 -0.997583 0.190040 0.995717 -1.728680 0.806952 -1.738312 0.811970
 1660 65 0.984318 -0.775691 0.115676 -0.791378 0.119189 0.999884 -1.545985 0.694877 -1.546160 0.694891
 150 15 0.373106 -0.289165 0.018749 -1.074327 0.229349 1.006737 -1.830718 0.849985 -1.813255 0.838786
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1010 10 0.941713 -0.907313 0.135314 -0.984080 0.156695 1.000777 -1.845861 0.867645 -1.843880 0.866402
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 1950 -10 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 -5 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 0 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 5 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000

1950 10 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 35 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 50 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 55 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 60 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 65 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 70 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 80 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 85 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1950 90 1.000000 -1.400000 0.490000 -1.400000 0.490000 1.000000 -1.400000 0.490000 -1.400000 0.490000
 1960 -90 0.999748 -0.925861 0.165241 -0.926098 0.165284 1.000012 -1.919517 0.921807 -1.919488 0.921790
 1960 -85 0.999750 -1.450285 0.506174 -1.450651 0.506303 1.000012 -1.911620 0.914409 -1.911591 0.914393
 1960 -80 0.999764 -1.526587 0.560569 -1.526944 0.560701 1.000000 -1.895023 0.900201 -1.895022 0.900201
 1960 -75 0.999767 -1.497951 0.524379 -1.498301 0.524503 1.000004 -1.913809 0.917670 -1.913800 0.917665
 1960 -70 0.999767 -0.903990 0.178165 -0.904206 0.178209 1.000012 -1.916618 0.919089 -1.916589 0.919073
 1960 -65 0.999786 -1.432657 0.456768 -1.432967 0.456870 1.000004 -1.932281 0.935546 -1.932271 0.935541
 1960 -60 0.999791 -1.038086 0.250965 -1.038311 0.251022 1.000012 -1.916747 0.919129 -1.916717 0.919112
 1960 -50 0.999836 -1.264397 0.307802 -1.264609 0.307861 1.000002 -1.915842 0.921145 -1.915839 0.921143
 1960 -30 0.999953 -0.986027 0.090205 -0.986069 0.090215 0.999995 -1.871379 0.881282 -1.871391 0.881289
 1960 -25 0.999982 -0.740174 -0.053790 -0.740180 -0.053787 1.000004 -1.869458 0.877019 -1.869448 0.877014
 1960 -15 1.000083 -1.202561 0.294470 -1.202426 0.294425 0.999994 -1.859093 0.873212 -1.859108 0.873221
 1970 70 1.000965 -1.238852 0.287039 -1.237419 0.286541 0.999962 -1.057710 0.397897 -1.057798 0.397946
 1960 -10 1.000132 -1.095881 0.218347 -1.095686 0.218288 0.999994 -1.850563 0.865159 -1.850578 0.865169
 1960 0 1.000231 -1.013725 0.168185 -1.013408 0.168094 0.999994 -1.843632 0.861521 -1.843646 0.861529
 1960 5 1.000278 -0.995320 0.158456 -0.994946 0.158350 0.999995 -1.844371 0.864677 -1.844384 0.864685
 1960 10 1.000320 -0.980630 0.152640 -0.980205 0.152521 0.999996 -1.846638 0.869336 -1.846650 0.869344
 1960 20 1.000388 -0.946679 0.143086 -0.946187 0.142954 0.999997 -1.849856 0.877097 -1.849863 0.877102
 1960 25 1.000412 -0.921882 0.136778 -0.921375 0.136647 0.999998 -1.845831 0.875450 -1.845836 0.875454
 1960 35 1.000441 -0.849444 0.115312 -0.848947 0.115198 1.000001 -1.823284 0.859577 -1.823284 0.859578
 1960 45 1.000455 -0.755041 0.087078 -0.754585 0.086989 1.000003 -1.780890 0.830772 -1.780886 0.830770
 1960 65 1.000462 -0.780191 0.114433 -0.779733 0.114332 1.000004 -1.546833 0.694620 -1.546828 0.694620
 1960 85 1.000412 -1.357561 0.451649 -1.356980 0.451447 1.000054 -1.042250 0.146437 -1.042123 0.146366
 1960 90 1.000412 -1.323314 0.430302 -1.322748 0.430110 1.000055 -1.047758 0.145756 -1.047630 0.145685
 1970 -90 0.999499 -0.925802 0.165291 -0.926273 0.165376 1.000024 -1.919554 0.921832 -1.919497 0.921799
 1970 -85 0.999502 -1.449132 0.505478 -1.449860 0.505735 1.000024 -1.911713 0.914485 -1.911656 0.914453
 1970 -80 0.999531 -1.525999 0.560304 -1.526710 0.560566 1.000001 -1.894953 0.900125 -1.894952 0.900125
 1970 -35 0.999834 -1.098997 0.163769 -1.099183 0.163811 0.999998 -1.927821 0.937480 -1.927827 0.937484
 1970 5 1.000553 -0.995694 0.158552 -0.994949 0.158341 0.999990 -1.844372 0.864686 -1.844399 0.864702
 1970 10 1.000638 -0.981032 0.152737 -0.980187 0.152500 0.999991 -1.846642 0.869346 -1.846665 0.869360
 1970 20 1.000772 -0.947125 0.143185 -0.946144 0.142921 0.999995 -1.849866 0.877109 -1.849880 0.877119
 1970 25 1.000819 -0.922335 0.136876 -0.921327 0.136615 0.999997 -1.845843 0.875463 -1.845852 0.875470
 1970 30 1.000854 -0.890994 0.127969 -0.889984 0.127720 0.999999 -1.837032 0.869540 -1.837036 0.869545
 1970 35 1.000879 -0.849873 0.115396 -0.848884 0.115169 1.000001 -1.823297 0.859587 -1.823296 0.859589
 1980 -75 0.999308 -1.497361 0.524253 -1.498397 0.524620 1.000012 -1.913797 0.917655 -1.913770 0.917640

1980 -70 0.999308 -0.903569 0.178088 -0.904211 0.178218 1.000036 -1.916684 0.919131 -1.916599 0.919082
 1980 -60 0.999378 -1.038045 0.251089 -1.038713 0.251259 1.000037 -1.916814 0.919171 -1.916726 0.919120
 1980 -55 0.999454 -1.329457 0.364718 -1.330196 0.364937 1.000008 -1.922401 0.926729 -1.922381 0.926718
 1980 -35 0.999752 -1.099003 0.163820 -1.099280 0.163883 0.999996 -1.927881 0.937540 -1.927890 0.937545
 1980 -25 0.999947 -0.741053 -0.053378 -0.741071 -0.053369 1.000013 -1.869425 0.876988 -1.869396 0.876974
 1980 -15 1.000246 -1.203304 0.294895 -1.202905 0.294760 0.999982 -1.859143 0.873284 -1.859188 0.873311
 1980 -10 1.000392 -1.096466 0.218576 -1.095887 0.218401 0.999982 -1.850559 0.865174 -1.850604 0.865201
 1980 -5 1.000540 -1.039199 0.182996 -1.038440 0.182775 0.999984 -1.845310 0.861077 -1.845352 0.861103
 1980 10 1.000952 -0.981431 0.152833 -0.980169 0.152479 0.999987 -1.846646 0.869355 -1.846680 0.869376
 1980 30 1.001275 -0.891439 0.128061 -0.889931 0.127690 0.999998 -1.837044 0.869552 -1.837051 0.869558
 1980 40 1.001336 -0.802337 0.100934 -0.800918 0.100634 1.000005 -1.803486 0.845340 -1.803478 0.845339
 1980 55 1.001369 -0.732143 0.089215 -0.730835 0.088965 1.000009 -1.721125 0.799663 -1.721108 0.799658
 1980 75 1.001307 -1.190949 0.331253 -1.189229 0.330702 1.000079 -0.899183 0.006936 -0.898996 0.006830
 1980 80 1.001165 -1.641874 0.672716 -1.639946 0.671917 1.000221 -0.610189 0.070210 -0.609795 0.070099
 1980 85 1.001225 -1.358116 0.451664 -1.356391 0.451066 1.000161 -1.042568 0.146544 -1.042189 0.146332
 1980 90 1.001224 -1.324143 0.430488 -1.322463 0.429919 1.000162 -1.047980 0.145842 -1.047599 0.145628
 1990 -75 0.999083 -1.497069 0.524190 -1.498444 0.524677 1.000016 -1.913789 0.917647 -1.913753 0.917627
 1990 -70 0.999082 -0.903367 0.178052 -0.904218 0.178225 1.000047 -1.916716 0.919152 -1.916603 0.919087
 1990 -40 0.999548 -1.145772 0.198160 -1.146306 0.198284 1.000001 -1.943914 0.950766 -1.943912 0.950766
 1990 -35 0.999670 -1.099009 0.163871 -1.099376 0.163954 0.999995 -1.927941 0.937599 -1.927953 0.937607
 1990 -30 0.999816 -0.986524 0.090496 -0.986688 0.090535 0.999981 -1.871438 0.881371 -1.871484 0.881399
 1990 -20 1.000126 -1.481801 0.522684 -1.481536 0.522561 0.999991 -1.890609 0.903412 -1.890632 0.903426
 1990 -15 1.000325 -1.203670 0.295104 -1.203141 0.294925 0.999976 -1.859168 0.873320 -1.859228 0.873356
 1990 -10 1.000520 -1.096755 0.218689 -1.095987 0.218456 0.999976 -1.850557 0.865181 -1.850617 0.865218
 1990 -5 1.000716 -1.039496 0.183086 -1.038489 0.182794 0.999978 -1.845306 0.861081 -1.845361 0.861115
 1990 0 1.000910 -1.014726 0.168460 -1.013477 0.168103 0.999978 -1.843626 0.861536 -1.843681 0.861570
 1990 5 1.001095 -0.996430 0.158739 -0.994955 0.158322 0.999979 -1.844376 0.864702 -1.844427 0.864734
 1990 10 1.001262 -0.981825 0.152928 -0.980151 0.152458 0.999982 -1.846649 0.869364 -1.846694 0.869392
 1990 15 1.001409 -0.965270 0.147208 -0.963438 0.146704 0.999986 -1.849622 0.874730 -1.849659 0.874754
 1990 20 1.001529 -0.948002 0.143380 -0.946061 0.142858 0.999990 -1.849885 0.877134 -1.849913 0.877152
 1990 30 1.001691 -0.891879 0.128152 -0.889878 0.127660 0.999998 -1.837057 0.869562 -1.837066 0.869571
 1990 45 1.001795 -0.755634 0.087095 -0.753835 0.086746 1.000011 -1.780846 0.830684 -1.780827 0.830680
 1990 50 1.001808 -0.724578 0.080872 -0.722844 0.080553 1.000012 -1.754301 0.815798 -1.754279 0.815792
 1990 55 1.001816 -0.732325 0.089222 -0.730590 0.088889 1.000013 -1.721099 0.799631 -1.721077 0.799626
 1990 60 1.001821 -0.755310 0.100333 -0.753544 0.099972 1.000013 -1.670788 0.773501 -1.670765 0.773495
 1990 75 1.001735 -1.190993 0.331170 -1.188712 0.330439 1.000105 -0.899375 0.006908 -0.899127 0.006768
 1990 80 1.001546 -1.642449 0.672924 -1.639891 0.671864 1.000293 -0.609955 0.070167 -0.609433 0.070020
 1990 85 1.001625 -1.358389 0.451672 -1.356101 0.450878 1.000214 -1.042724 0.146597 -1.042221 0.146315
 1990 90 1.001624 -1.324552 0.430580 -1.322323 0.429824 1.000215 -1.048090 0.145884 -1.047584 0.145601

附录 N
(资料性)
实时制作时元数据传输系统的案例

N.1 背景与应用范围

音频实时制作场景下实现元数据传输的实际应用和落地。

N.2 技术架构设计原理

附录 N 提出了一种应用于元数据传输的方法，用于制作端产生元数据后的完整传输。根据元数据的定义，元数据为 ADM，根据 ADM 模型建议，元数据使用 XML 作为其规范语言，但如果需要，可以将其映射到其他语言，如 JSON。为测试此传输方式，构建如图 N.1 所示工作流程：

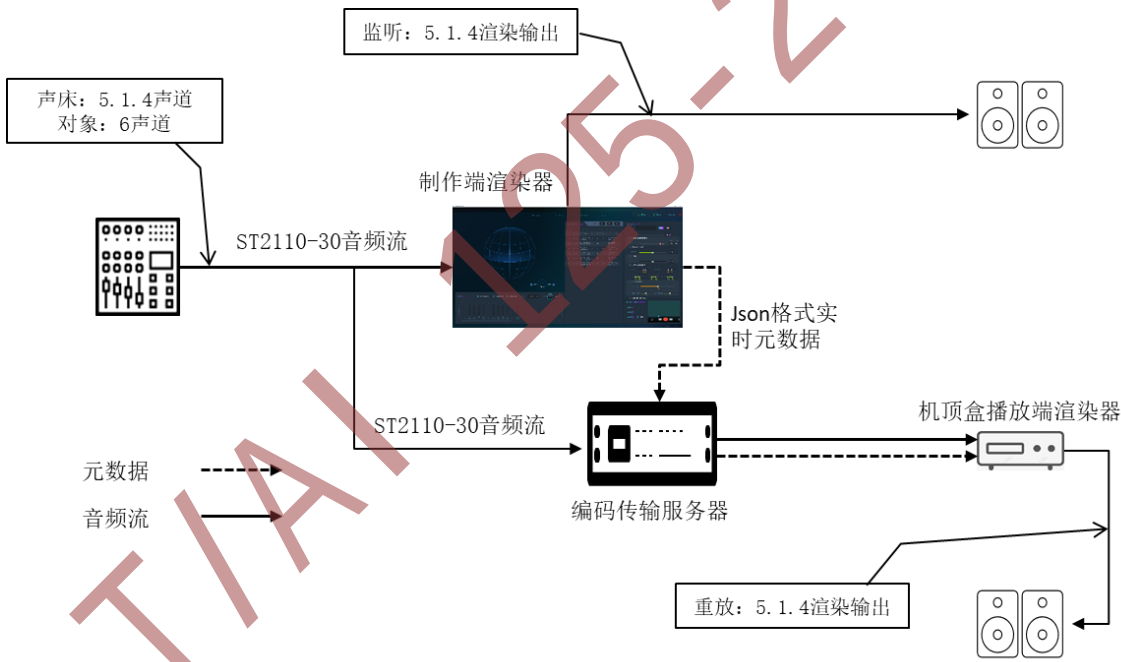


图 N.1 实时制作音频元数据传输示例

- 转播音频信号为直接扬声器类型 5.1.4 声道与对象类型 6 声道，处理过程如下：
- 1) 此音频信号流基于 ST2110-30 传输，分两路输入：其一直接输入编码传输服务器；另一输入制作端渲染器，当信号进入渲染器，渲染器解析输入信号的元数据与音频信号；
 - 2) 渲染器将解析元数据与音频数据进行渲染，并生成 5.1.4 扬声器布局的渲染音频输出；同时将解析出来的元数据进行两种处理：存成文件式的音频+元数据，将元数据下发至编码传输服务器；
 - 3) 下发的元数据为完整的 XML 格式的元数据文件；制作端渲染器作为客户端 C 与编码传输服务器作为服务端 S，建立基础的 C/S 服务，建立 HTTP 服务端口。C 端将元数据以

- JSON 流格式进行传输至 S 端；
- 4) S 端收到 JSON 格式元数据解析后，进入元数据编码预处理：将完整元数据的部分参数取出（如：audioProgrammeID, AudiopackformatID 等）；
 - 5) S 端将取得的元数据参数与从 ST2110-30 传输取得的音频数据进行编码封装形成流传输；
 - 6) 机顶盒将收到的信号流进行解码，得到音频流与元数据参数流；机顶盒对元数据参数流进行元数据还原、生成可进行渲染处理的元数据，将元数据流与音频流分别送入播放端渲染器的元数据接口与音频接口；
 - 7) 播放端渲染器进行 5.1.4 的渲染音频输出。
- 使用 HTTP 的 C/S 服务传输 JSON 格式映射的 XML 元数据，实现方法非常简单。

N.3 传输语法

N.3.1 概述

元数据发送采用 JSON 封装。主要包含元数据信息和描述信息。采用 http POST 发送方式，JSON 作为 http 的 body 数据。

N.3.2 http头和元数据JSON语法格式

http 采用标准协议语法格式，...表示可扩展的其他字段，其语法见表 N.1：

表 N.1 标准http header（）语法

语法	比特数	助记符
httpheader（）		
{		
Accept		
Content-Type		
Content-Length		
Connection		
...		
}		

JSON 具体语法格式，见表 N.2：

表 N.2 Json 语法

语法	比特数	助记符
JsonSendAdmInfo_t		
{		
cmd	8	
xmlType	8	
xmlValue	8-160	

表 N.2 （续）

语法	比特数	助记符
JsonSendAdmInfo_t () = default;		
JsonSendAdmInfo_t& operator= (const JsonSendAdmInfo_t& src) {		
if (&src == this)		
return *this;		
this->cmd = src.cmd;		
this->xmlType = src.xmlType;		
this->xmlValue = src.xmlValue;		
return *this;		
}		
void copy (const JsonSendAdmInfo_t& src) {		
*this = src;		
}		
XPack (O (cmd, xmlType, xmlValue));		
}		
//send http post		
JsonSendAdmInfo_t jsonadmininfo;		
jsonadmininfo.xmlValue = strjson;		
string strsendJson = JsonHandler::toJson (jsonadmininfo);		
string strResptmp = "";		
if (httpClient_.request_post (renderManger::GetInstance () ->m_dhserveraddr.c_str (), strsendJson.c_str (), strResptmp))		

最终传输的元数据服务端打印信息为完整元数据的字符串，见表 N.3。

表 N.3 元数据服务端打印信息

完整元数据的字符串
<?xml version="1.0" encoding="utf-8"?><ebuCoreMain xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns="urn:ebu:metadata-schema:ebuCore_2014" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" schema="EBU_CORE_20140201.xsd" xml:lang="en"><coreMetadata><format><audioFormatExtended><audioProgramme audioProgrammeID="APR_1001"audioProgrammeName="Default"><audioContentIDRef>ACO_1001</audioContentIDRef></audioProgramme><audioContent audioContentID="ACO_1001" audioContentName="Default"><audioObjectIDRef>AO_1001</audioObjectIDRef><audioObjectIDRef>AO_1002</audioObjectIDRef><audioObjectIDRef>AO_1003</audioObjectIDRef><audioObjectIDRef>AO_1004</audioObjectIDRef><audioObjectIDRef>AO_1005</audioObjectIDRef><audioObjectIDRef>AO_1006</audioObjectIDRef><audioObjectIDRef>AO_1007</audioObjectIDRef></audioContent><audioObject audioObjectID="AO_1001" audioObjectName="5.1.4 Bed"><audioPackFormatIDRef>AP_00010005</audioPackFormatIDRef><audioTrackUIDRef>ATU_00000001</audioTrackUIDRef><audioTrackUIDRef>ATU_00000002</audioTrackUIDRef><audioTrackUIDRef>ATU_00000003</audioTrackUIDRef><audioTrackUIDRef>ATU_00000004</au


```

dioTrackUIDRef><audioTrackUIDRef>ATU_00000005</audioTrackUIDRef><audioTrackUIDRef>ATU_000
00006</audioTrackUIDRef><audioTrackUIDRef>ATU_00000007</audioTrackUIDRef><audioTrackUIDRe
f>ATU_00000008</audioTrackUIDRef><audioTrackUIDRef>ATU_00000009</audioTrackUIDRef><audioTr
ackUIDRef>ATU_0000000a</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1002"
audioObjectName="CHN"><audioPackFormatIDRef>AP_00031001</audioPackFormatIDRef><audioTrackU
IDRef>ATU_0000000b</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1003" audi
oObjectName="OBJ2"><audioPackFormatIDRef>AP_00031002</audioPackFormatIDRef><audioTrackUIDR
ef>ATU_0000000c</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1004" audioObj
ectName="OBJ3"><audioPackFormatIDRef>AP_00031003</audioPackFormatIDRef><audioTrackUIDRef>
ATU_0000000d</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1005" audioObject
Name="OBJ4"><audioPackFormatIDRef>AP_00031004</audioPackFormatIDRef><audioTrackUIDRef>AT
U_0000000e</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1006" audioObjectNa
me="OBJ5"><audioPackFormatIDRef>AP_00031005</audioPackFormatIDRef><audioTrackUIDRef>ATU_0
000000f</audioTrackUIDRef></audioObject><audioObject audioObjectID="AO_1007" audioObjectName="
OBJ6"><audioPackFormatIDRef>AP_00031006</audioPackFormatIDRef><audioTrackUIDRef>ATU_00000
010</audioTrackUIDRef></audioObject><audioPackFormat audioPackFormatID="AP_00031001" audioPac
kFormatName="CHN" typeLabel="0003" typeDefinition="Objects"><audioChannelFormatIDRef>AC_0003
1001</audioChannelFormatIDRef></audioPackFormat><audioPackFormat audioPackFormatID="AP_00031
002" audioPackFormatName="OBJ2" typeLabel="0003" typeDefinition="Objects"><audioChannelFormatI
DRef>AC_00031002</audioChannelFormatIDRef></audioPackFormat><audioPackFormat audioPackFormat
ID="AP_00031003" audioPackFormatName="OBJ3" typeLabel="0003" typeDefinition="Objects"><audioC
hannelFormatIDRef>AC_00031003</audioChannelFormatIDRef></audioPackFormat><audioPackFormat au
dioPackFormatID="AP_00031004" audioPackFormatName="OBJ4" typeLabel="0003" typeDefinition="Obj
ects"><audioChannelFormatIDRef>AC_00031004</audioChannelFormatIDRef></audioPackFormat><audioP
ackFormat audioPackFormatID="AP_00031005" audioPackFormatName="OBJ5" typeLabel="0003" typeD
efinition="Objects"><audioChannelFormatIDRef>AC_00031005</audioChannelFormatIDRef></audioPackFo
rmat><audioPackFormat audioPackFormatID="AP_00031006" audioPackFormatName="OBJ6" typeLabel=
"0003" typeDefinition="Objects"><audioChannelFormatIDRef>AC_00031006</audioChannelFormatIDRef>
</audioPackFormat><audioChannelFormat audioChannelFormatID="AC_00031001" audioChannelFormatN
ame="CHN" typeLabel="0003" typeDefinition="Objects"><audioBlockFormat audioBlockFormatID="AB_
00031001_00000001" rtime="00:00:00.000000000"><position coordinate="azimuth">-0.000000</position><
position coordinate="elevation">0.000000</position><position coordinate="distance">1.000000</position><
width>0.000000</width><height>0.000000</height><depth>0.000000</depth><gain gainUnit="dB">0.0000
00</gain></audioBlockFormat></audioChannelFormat><audioChannelFormat audioChannelFormatID="AC_
00031002" audioChannelFormatName="OBJ2" typeLabel="0003" typeDefinition="Objects"><audioBlockF
ormat audioBlockFormatID="AB_00031002_00000001" rtime="00:00:00.000000000"><position coordinate
="azimuth">0.000000</position><position coordinate="elevation">0.000000</position><position coordinate
="distance">1.400000</position><width>0.000000</width><height>0.000000</height><depth>0.000000</de
pth><gain>1.000000</gain></audioBlockFormat></audioChannelFormat><audioChannelFormat audioChann
elFormatID="AC_00031003" audioChannelFormatName="OBJ3" typeLabel="0003" typeDefinition="Object

```

```

s"><audioBlockFormat audioBlockFormatID="AB_00031003_00000001" rtime="00:00:00.000000000"><po
sition coordinate="azimuth">0.000000</position><position coordinate="elevation">0.000000</position><po
sition coordinate="distance">1.000000</position><width>0.000000</width><height>0.000000</height><dep
th>0.000000</depth><gain gainUnit="dB">0.000000</gain></audioBlockFormat></audioChannelFormat><a
udioChannelFormat audioChannelFormatID="AC_00031004" audioChannelFormatName="OBJ4" typeLabel
="0003" typeDefinition="Objects"><audioBlockFormat audioBlockFormatID="AB_00031004_00000001" rt
ime="00:00:00.000000000"><position coordinate="azimuth">0.000000</position><position coordinate="ele
vation">0.000000</position><position coordinate="distance">0.000000</position><width>0.000000</widt
h><height>0.000000</height><depth>0.000000</depth><gain gainUnit="dB">0.000000</gain></audioBloc
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n coordinate="distance">1.000000</position><width>0.000000</width><height>0.000000</height><depth>
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Definition="PCM"><audioChannelFormatIDRef>AC_00031002</audioChannelFormatIDRef><audioTrackFo
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treamFormatID="AS_00031003" audioStreamFormatName="OBJ3" formatLabel="0001" formatDefinition=
"PCM"><audioChannelFormatIDRef>AC_00031003</audioChannelFormatIDRef><audioTrackFormatIDRe
f>AT_00031003_01</audioTrackFormatIDRef></audioStreamFormat><audioStreamFormat audioStreamFor
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31004_01</audioTrackFormatIDRef></audioStreamFormat><audioStreamFormat audioStreamFormatID="A
S_00031005" audioStreamFormatName="OBJ5" formatLabel="0001" formatDefinition="PCM"><audioCha
nnelFormatIDRef>AC_00031005</audioChannelFormatIDRef><audioTrackFormatIDRef>AT_00031005_01<
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```

```

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f>AP_00031003</audioPackFormatIDRef></audioTrackUID><audioTrackUID UID="ATU_0000000e"><au
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rmatIDRef></audioTrackUID><audioTrackUID UID="ATU_00000010"><audioTrackFormatIDRef>AT_0003
1006_01</audioTrackFormatIDRef><audioPackFormatIDRef>AP_00031006</audioPackFormatIDRef></aud

```

ioTrackUID></audioFormatExtended></format></coreMetadata></ebuCoreMain>

T/AI 125-2023

附 录 0

(资料性)

非 GY/T316 标准扬声器布局的渲染器

0.1 技术架构设计原理

标准化扬声器布局的渲染器对于新一代音频系统的真正普及应用非常重要,对于在广播系统框架内开发的系统的内容制作和质量评估提出了技术要求。但实际应用中的扬声器回放布局通常是非标准化的,即非 GY/T 316 (或 ITU-R BS. 2051)。

附录 O 提出了一种应用于渲染器的算法,用于渲染输出非标准扬声器布局回放。非标扬声器布局坐标系采用与 GY/T 316 (或 ITU-R BS. 2051 标准) 布局同样坐标系,附录 O 提出非标准扬声器布局为:

多个独立通道音箱,个数在 6 个以上,摆放位置不遵循 GY/T316 的距离、角度或高度规定。

对于以上非标布局,建议扬声器都能对测试者或仪器发出直达声。处理流程图如图 O.1:

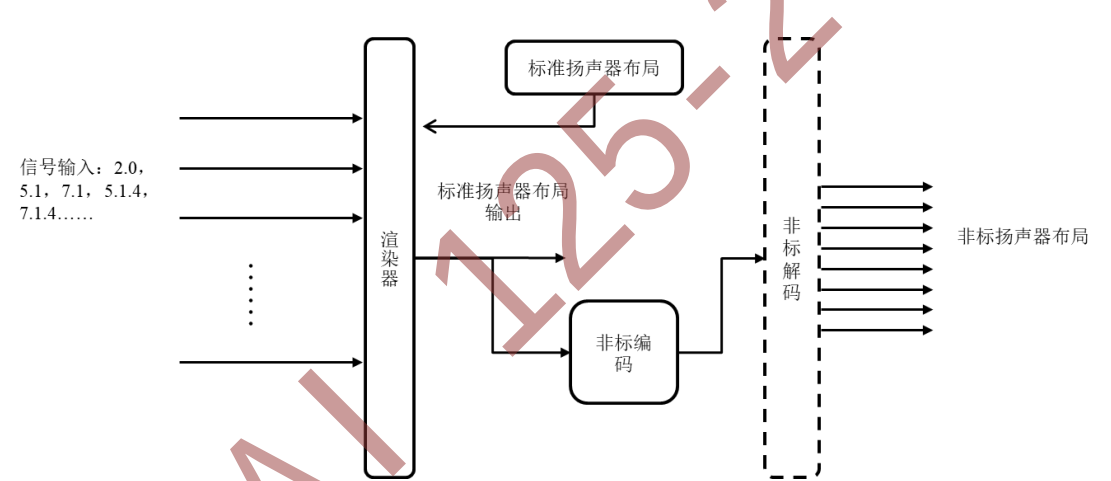


图 0.1 非标渲染原理

对于信号输入,面向扬声器输出渲染器(ID2),支持将不对称的输入、输出进行渲染,将输入信号的声道格式与渲染输出声道格式解耦;此项功能在 10.7 节中有详述。

对于渲染信号输出,对于标准扬声器布局配置,渲染器算法将直接渲染输出;而非标配置时,算法先将标准输出(如 7.1.4 的渲染输出)进行非标编码处理,再依据典型的非标类型进行解码输出(如: 5.1.2),得到非标准扬声器布局的渲染输出结果。

0.2 设计技术方案

附录O中的补充方案依然适用于使用ADM (ITU-R BS.2076) 音频模型的渲染器。对于非对称输入、输出信号的渲染参考10.7节。图O.2主要为面向非标布局的设计框架。

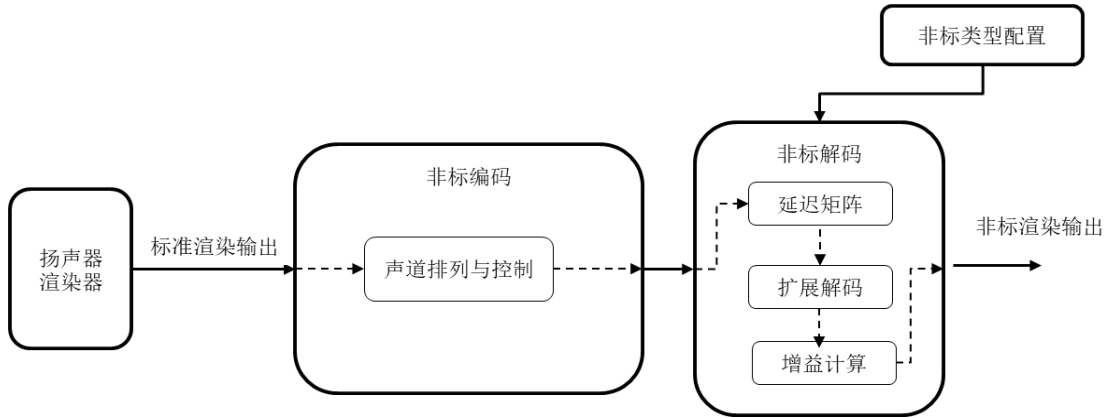


图 0.2 非标声道编码与解码

图 0.2 描述了在标准渲染基础上，对相应非标类型布局配置时的输出渲染框架。主要处理模块分为：

1) 非标编码：

从声道排列与控制模块中起始，将标准渲染输出信号 s 编码为环境信号 X_{nm} ，将信号与用权重 $Y_n^m(\theta_s)$ 表示信号方向 θ_s 的编码器相乘，表示为：

$$X_{nm}(t) = Y_n^m(\theta_s)s(t) \quad \cdots \cdots (O.1)$$

式中：

n ——球谐函数的阶数；

m ——球谐函数的度数，可用矢量表示为式 (O.2)。

$$\mathbf{X}_N = \mathbf{y}_N(\theta_s)s \quad \cdots \cdots (O.2)$$

其中使用了 $(N+1)^2$ 个分量的列矩阵向量： $\mathbf{y}_N = [Y_0^0(\theta_s), Y_1^{-1}(\theta_s), \dots, Y_N^N(\theta_s)]^T$ ， N 为阶数。此编码过程将形成多声道音频信号。

2) 非标解码输出：

各声道的数据对齐在上述延迟列矩阵中动态计算，然后进行声道扩展解码，再进行各声道增益的计算。增益计算模块使用声道排列数据将音频信号编码，这种方法的优点在于，对后续的非标布局配置系数执行 Panning，可使用比音频采样频率低得多的速率，因此更有效。对不同非标类型，解码模块把每个扬声器对应的方位角，俯仰角和距离进行相应的配置。

$\mathbf{X}_N$ 中的环境声信号由旁瓣抑制权重 $\mathbf{a}_N = [a_0, a_1, a_1, a_2, \dots, a_N]^T$ 加权，用对角矩阵 $\text{diag}\{\mathbf{a}_N\}$ 乘法表示，然后使用公式 (O.3) 与 (O.4) 求解信号 x ：

$$\mathbf{D} = \sqrt{\frac{4\pi}{L}} [\mathbf{y}_N(\theta_1), \dots, \mathbf{y}_N(\theta_L)]^T = \sqrt{\frac{4\pi}{L}} \mathbf{Y}_N^T \quad \cdots \cdots (O.3)$$

则

$$\mathbf{x} = \mathbf{D} \text{diag}\{\mathbf{a}_N\} \mathbf{X}_N \quad \cdots \cdots (O.4)$$

式中：

$\mathbf{D}$ ——非标采样解码器；确认空格格式，破折号统一成没有断开的

L ——解码的扬声器的个数；

x ——解码信号。

总的来说，编码公式（O.2）和解码公式（O.3）的系统可以合写成公式（O.5），以产生非标信号输出的扬声器增益：

$$g = \mathbf{D} \text{diag}\{\mathbf{a}_N\} \mathbf{y}_N(\theta_s) = \sqrt{\frac{4\pi}{L}} \mathbf{Y}_N^T \text{diag}\{\mathbf{a}_N\} \mathbf{y}_N(\theta_s) \quad \cdots \cdots (\text{O.5})$$

式中：

g ——非标信号输出的扬声器增益。

为了优化非标扬声器布局，即需要将解码信号按球面形状均匀分布，解码器 $\mathbf{D}$ 须另定义成实际物理扬声器上的VBAP合成，该合成信号输出则可以定义成写成虚拟扬声器 θ 的积分：

$$\mathbf{D} = \int g_{VBAP}(\theta) \mathbf{y}_N^T(\theta) d\theta \quad \cdots \cdots (\text{O.6})$$

此处 VBAP 扬声器增益函数 $g_{VBAP}(\theta)$ 理解为转换为球谐系数，通过此球谐函数，则可将信号解码到均匀分布在球体上的虚拟扬声器，或者说均匀地产生虚拟扬声器增益：

$$g = \int g_{VBAP}(\theta) g_{AMBI}(\theta) d\theta = \int g_{VBAP}(\theta) \mathbf{y}_N^T(\theta) \text{diag}\{\mathbf{a}_N\} \mathbf{y}_N(\theta_s) d\theta \quad \cdots \cdots (\text{O.7})$$

此积分在非标扬声器布局上可提供最为匹配的最均匀的解码（渲染）输出。

解码输出的参考界面如图 O.3 所示：

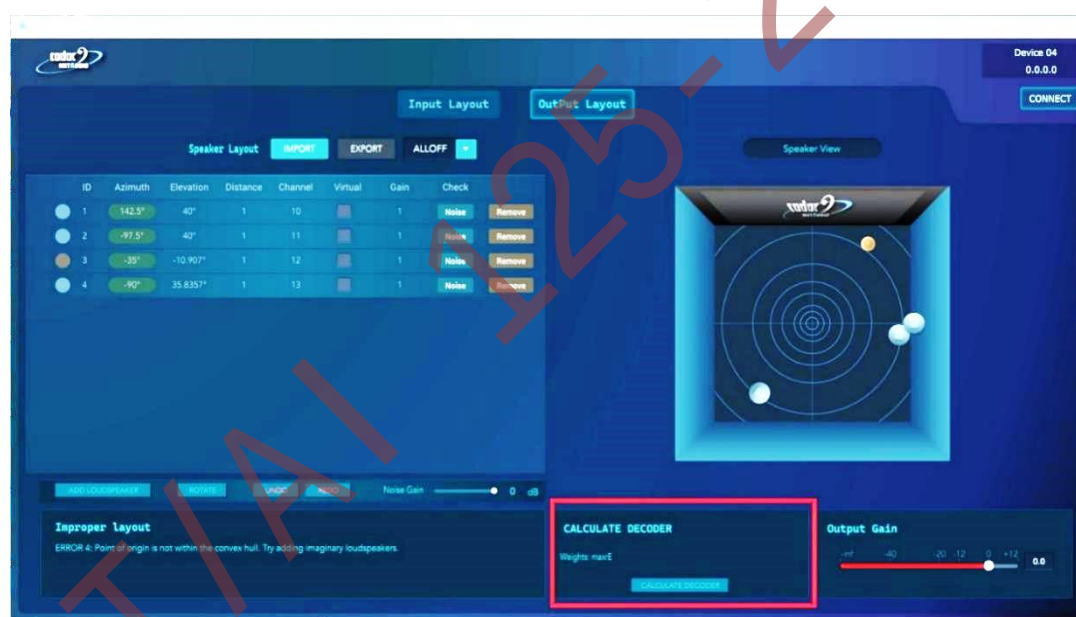


图 O.3 非标解码输出的参考界面

在输出布局中，按照实际数量添加输出音箱，通过实际测量后把每个音箱对应的方位角，俯仰角和距离输入进坐标中进行非标扬声器布局，即可通过解码计算分配渲染输出结果，如图 O.4 所示：

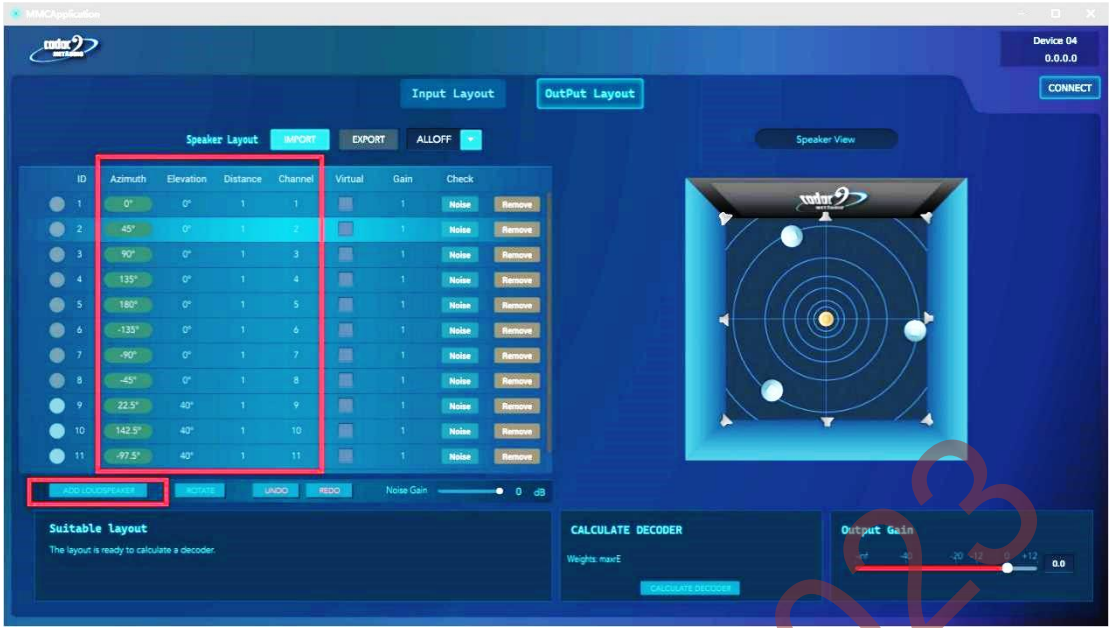


图 0.4 非标渲染输出结果

当应用场景不需要精确且专业级的渲染效果时，可预设一些常用模式，直接导入预设方位角，俯仰角和距离配置。

为保留更多的音频对象信息（如位置、角度），渲染器标准输出到编码的声道数尽量多（如附录 O 中所述的 7.1.4 声道）；相应地，对于非标编码与解码通道也要求较多，如 16、32、64 通道，则要求实现时具有足够的算力支持多声道输入、输出的计算处理。

附 录 P
(资料性)
Surface 子元素支持的材料类型

P.1 概述

Surface 子元素支持的 25 种材料类型见表 P.1。

表P.1 25种材料类型

材料序号	材料标签
0	Default
1	Brick
2	BrickPainted
3	Carpet
4	CarpetHeavy
5	CarpetHeavyPadded
6	CeramicTile
7	Concrete
8	ConcreteRough
9	ConcreteBlock
10	ConcreteBlockPainted
11	Curtain
12	Foliage
13	Glass
14	GlassHeavy
15	Grass
16	Gravel
17	GypsumBoard
18	PlasterOnBrick
19	PlasterOnConcreteBlock
20	Soil
21	SoundProof
22	Snow
23	Steel
24	Water
25	WoodThin

附录 Q

(资料性)

扩展元数据示例代码

Q.1 扩展元数据示例代码

完整的扩展元数据示例代码如下：

```
<vrExt>
  <version>0.0.1</version>
  <chunkID>bd_0001</chunkID>
  <name>ByteDance expanded metadata</name>
  <chunkSize>1024</chunkSize>
  <level>4</level>
  <checksum>validation code</checksum>
  <presenceInfo descriptor="content" sampleRate="48000">
    <audioProgrammeReferID>APR_1001</audioProgrammeReferID>
    <isEncoded>0</isEncoded>
    <avDataAligned>0</avDataAligned>
    <frameRate>1024</frameRate>
    <loudnessGain>1</loudnessGain>
    <mergeMode>0</mergeMode>
    <instanceReferID>INS_0001_0001</instanceReferID>
    <instanceReferID>INS_0003_0001</instanceReferID>
    <instanceReferID>INS_0004_0001</instanceReferID>
  </presenceInfo>
  <instance id="INS_0001_0001" type="0001" typeLabel="DirectSpeakers">
    <audioChannelFormatRefID>AC_00011001</audioChannelFormatRefID>
    <unitInfo id="INS_0001_0001_00000001">
      <label>FrontLeft</label>
    </unitInfo>
  </instance>
  <instance id="INS_0004_0001" type="0004" typeLabel="HOA">
    <audioChannelFormatRefID>AC_00041001</audioChannelFormatRefID>
    <unitInfo id="INS_0004_0001_00000001">
      <order>0</order>
      <degree>0</degree>
      <normalization>0</normalization>
    </unitInfo>
  </instance>
  <instance id="INS_0003_0001" type="0003" typeLabel="Objects">
    <unitInfo id="INS_0003_0001_00000001" start="00:00:00.00"
duration="00:00:10.00">
      <position coordinate="azimuth">0.00</position>
      <position coordinate="elevation">0.00</position>
```

```

        <position coordinate="distance">1.00</position>
    </unitInfo>
</instance>
<staticControl>
    <ambisonicOrder>7</ambisonicOrder>
    <acousticEnv type="01" typeLabel="Physical">
        <earlyReflectionGain>1.00</earlyReflectionGain>
        <lateReverbGain>1.00</lateReverbGain>
        <lowFreqProFlag>1</lowFreqProFlag>
        <convolutionReverbType>0</convolutionReverbType>
        <surface material="0" materialLabel="brick">
            <vertex x="2" y="-2" z="-2"/>
            <vertex x="-2" y="-2" z="-2"/>
            <vertex x="-2" y="-2" z="2"/>
            <vertex x="2" y="-2" z="2"/>
            <vertex x="2" y="2" z="-2"/>
            <vertex x="-2" y="2" z="-2"/>
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            <vertex x="2" y="2" z="2"/>
            <indice index1="0" index2="1" index3="2"/>
            <indice index1="0" index2="2" index3="3"/>
            <indice index1="1" index2="5" index3="6"/>
            <indice index1="1" index2="6" index3="2"/>
            <indice index1="5" index2="4" index3="7"/>
            <indice index1="5" index2="7" index3="6"/>
            <indice index1="4" index2="0" index3="3"/>
            <indice index1="4" index2="3" index3="7"/>
            <indice index1="0" index2="4" index3="5"/>
            <indice index1="0" index2="5" index3="1"/>
            <indice index1="3" index2="2" index3="6"/>
            <indice index1="3" index2="6" index3="7"/>
            <absorption band1="0.025" band2="0.028" band3="0.051"
                band4="0.070" band5="1.000" band6="1.000"
                band7="1.000" band8="1.000"/>
            <scattering band1="0.100" band2="0.100" band3="0.100"
                band4="0.100" band5="0.100" band6="0.100"
                band7="0.100" band8="0.100"/>
        </surface>
    </acousticEnv>
</renderInfo>
    <targetDevice>0</targetDevice>
    <hrtfType>0</hrtfType>
    <headphoneType>0</headphoneType>

```

```

    <audioEffect>
    <EQ index="1">
        <item type="7" typeLabel="typeLabel" frequency="400.00"
bandWidth="100.00" gain="2.00"/>
    </EQ>
    <DRC index="2" attackTime="0.00" releaseTime="0.25"
threshold="-24." preGain="0.00" postGain="0.00"/>
    <Gain index="3" gain="1">
    </audioEffect>
</rendererInfo>
</staticControl>
<dynamicControl>
    <listener>
        <interpolatedType>0</interpolatedType>
        <coordinate start="00:00:00.00" duration="00:00:01.00">
            <position x="0.00" y="0.00" z="1.00"/>
            <front x="0.00" y="0.00" z="1.00"/>
            <up x="0.00" y="1.00" z="0.00"/>
        </coordinate>
        <coordinate start="00:00:01.00" duration="00:00:01.00">
            <position x="0.00" y="0.00" z="1.00"/>
            <front x="0.00" y="0.00" z="1.00"/>
            <up x="0.00" y="1.00" z="0.00"/>
        </coordinate>
    </listener>
</dynamicControl>
</vrExt>

```

附录 R
(规范性)
渲染器 ID1 的原理

R.1 渲染器引擎技术

R.1.1 处理链路

耳机渲染处理链路如图R.1所示。渲染器以块为单位处理音频数据，块的大小应在初始化时确定并不再更改。在实时处理链路上，应先对元数据进行解析并根据元数据调整场景信息，以获得相应的渲染效果。

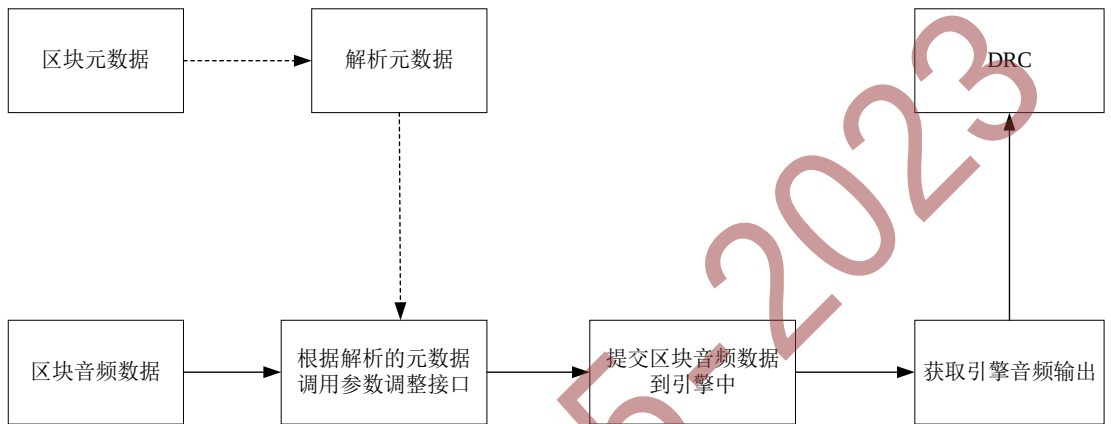


图 R.1 处理链路

R.1.2 对象音频的渲染

对象音频的渲染流程如图R.2。

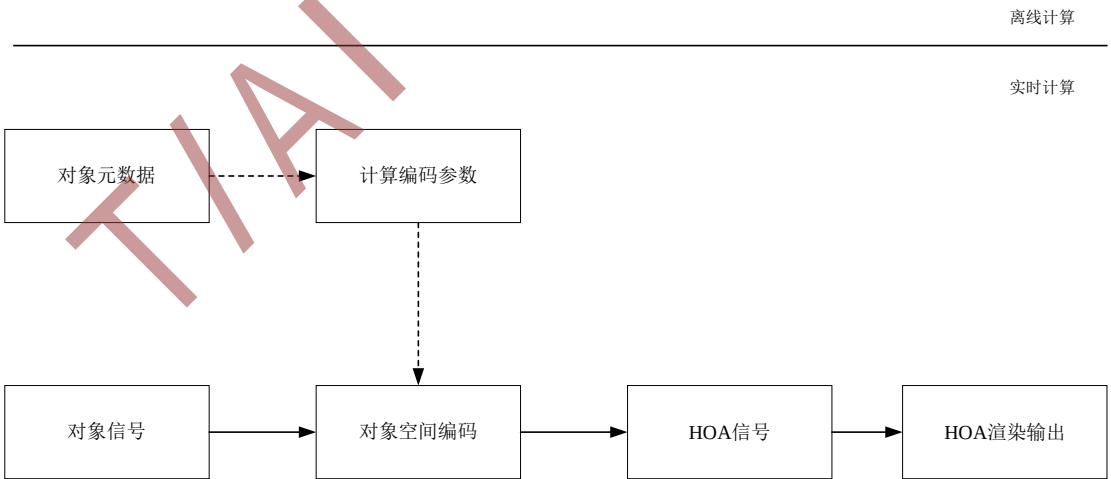


图 R.2 对象音频的渲染流程

渲染对象信号时统一将其编码为HOA信号，以HOA信号作为中介介质信号存储，待编码过程完成后，使用头传输函数HRTF（制作球谐HRTF参考附录J，HRTF库来源参考附录A，对HRTF库进行插值参考附录B）将HOA信号解码到双耳信号。Ambisonic原理参考附录E。

R. 1. 3 HOA 音频的渲染

渲染器支持1-7阶HOA信号的渲染，ADM中HOA信号的声道规定了对应order和degree，以作为渲染控制参数直接使用，对于归一化化方法，渲染器需要至少支持N3D和SN3D两种方式，FuMa的归一化化需要预先进行转换。

渲染器支持同时渲染多个HOA信号，在渲染处理时如果有多个Channel有同样的order和degree时，这两个信号会被混合。

通过双耳回放HOA信号的流程如图R.3。渲染器中自带了一组1~7阶的球谐HRIR。在渲染过程中，首先通过listener姿态确定旋转矩阵，并转换HOA信号，在针对每个HOA的声道，和对应的HRIR进行频域卷积。对于所有degree大于0的声道，将卷积结果同时加在左右信号上。对于所有degree<0的声道，将卷积结果加在左耳信号并减在右耳信号上获得双耳渲染的信号。

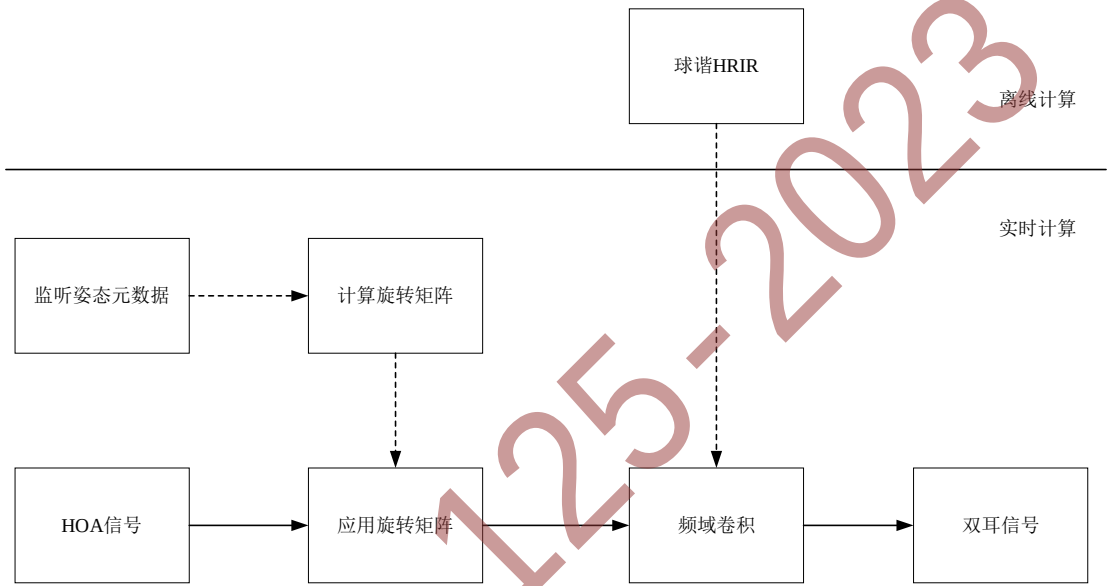


图 R. 3 HOA 信号渲染输出到双耳

需要注意的是，HOA信号本身是Ambisonic信号，不需要像对象信号一样进行Ambisonic编码，只需要将HOA信号按通道顺序叠加到中介信号上用于Ambisonic解码以输出双耳信号。

R. 1. 4 声道音频的渲染

由于多声道音频声源的位置是固定的，只需要在初始化的时候设定。相对于其他多声道双耳渲染方法（参考附录H），将多声道音频的每个通道当做一个单通道的对象音频处理，渲染过程无需更新位置，因此多声道音频的渲染流程可以复用对象音频的渲染，渲染流程如图R.4:

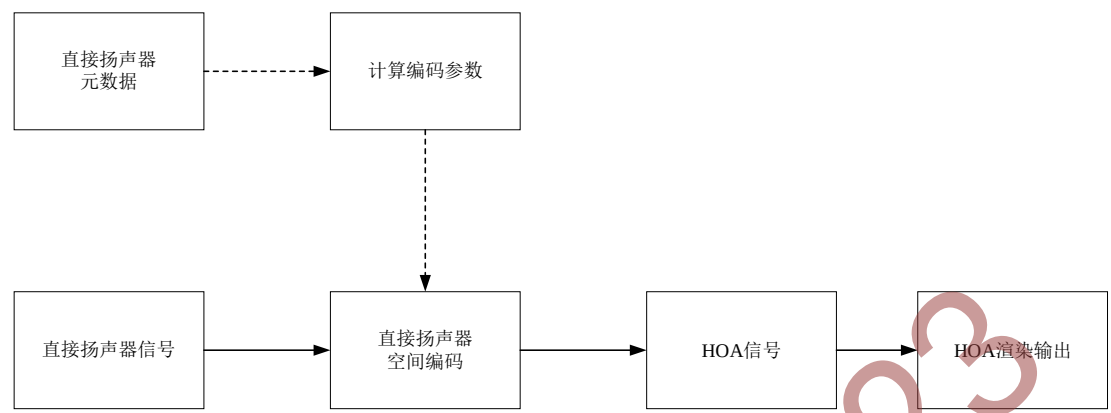


图 R. 4 声道信号渲染输出到耳机

R. 2 6DoF渲染规范

人头的自由度分为：既有位移又有旋转的6DoF、只有旋转的3DoF。当听着头部发生转动或位移时，声源与头部相对方向会产生变化。因此，6DoF空间声场技术就需要获得更复杂的人头自由度，示意图如图R.5。

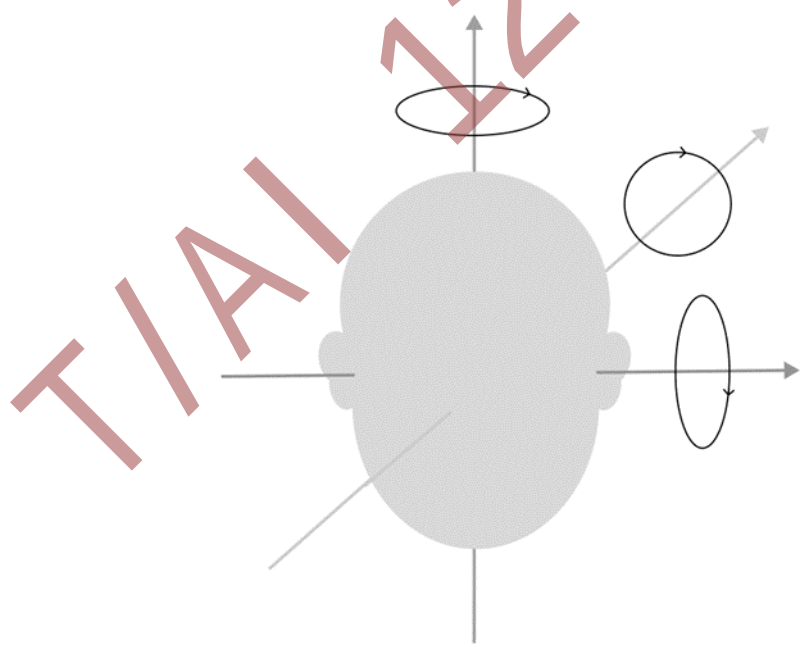


图 R. 5 6DoF 自由度示意图

听者位置和声源位置变化均会导致声音的方位感产生变化，听者的移动等同声源的反向移动，将声源的坐标和听者的坐标变换到同一个参考坐标系，得到声源相对于听者的方向，此方向向量可以用于表示声源在球谐域的声场分布。将以上所得的坐标信息传入双耳渲染器

用于声场计算，渲染之后的声音就携带了声源的位置信息、听者的位置信息和姿态信息，即6DoF渲染能力。

6DoF渲染框架如图R.6:

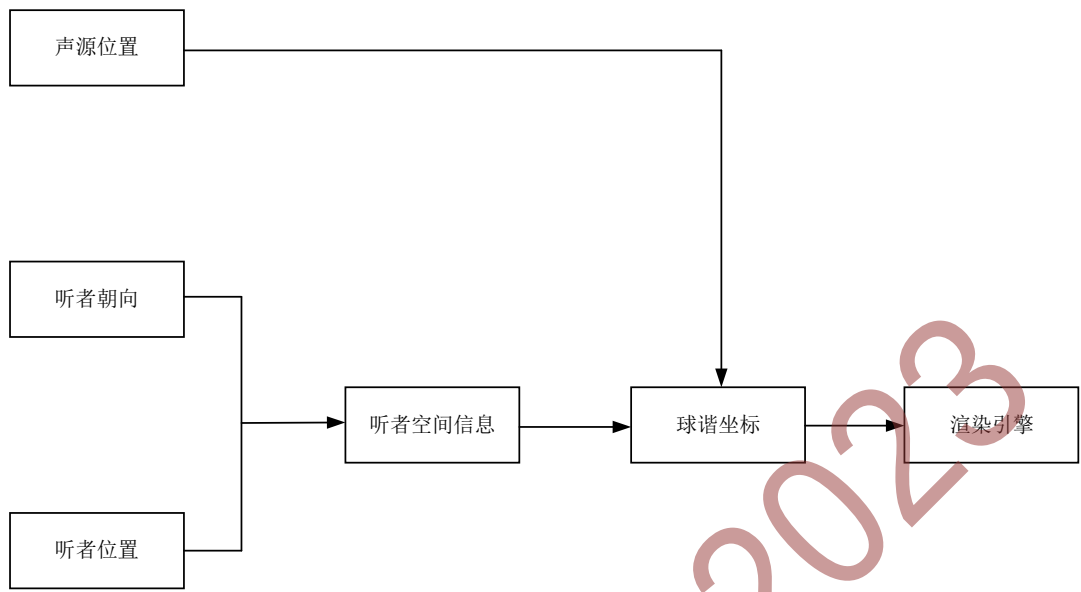


图 R. 6 6DoF 技术框架

位置变换关系如下:

$$R_r = R_f \cdot R_u \qquad \dots\dots (R.7)$$

$$R_l = \begin{bmatrix} R_r & R_f & R_u \end{bmatrix} \qquad \dots\dots (R.8)$$

$$P = R_l^{-1} \cdot (P_s - P_l) \qquad \dots\dots (R.9)$$

- 式中:
- P ——位置;
 - R ——旋转;
 - R ——正右方向;
 - F ——正前方;
 - U ——正上方;
 - S ——声源;
 - L ——听者。

R. 3 动态混响规范

常用的静态混响技术例如人工混响和采样卷积混响分别在附录C及附录K中列出，而动态混响技术的目的是在双耳渲染的基础上模拟真实场景的环境混响效果，使双耳渲染更真实。动态混响技术框架如图R.7:

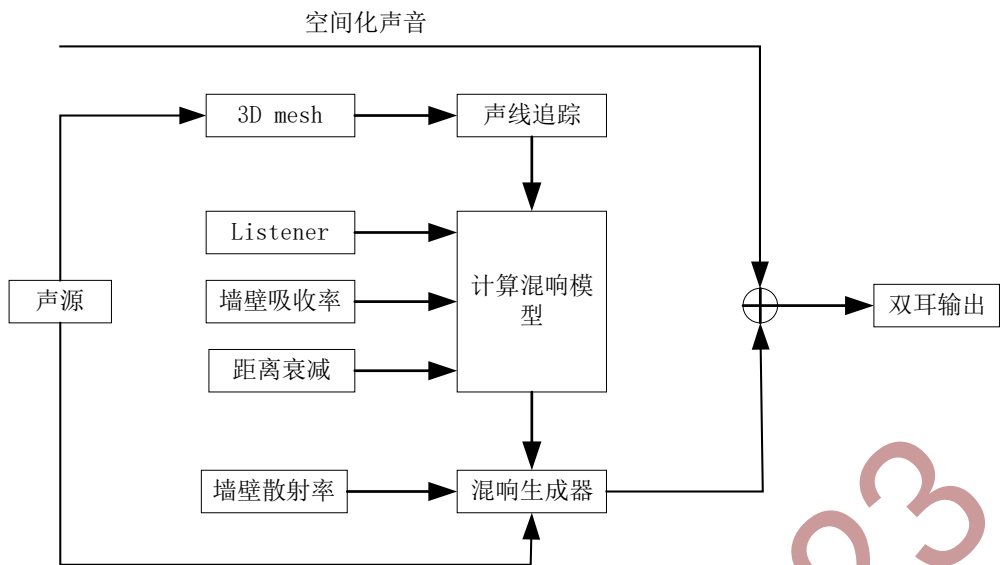


图 R.7 动态混响原理图

将声源发出的声音假设为从声源发出的若干条声线，在场景中模拟空气传播、反射、折射等物理现象，收集最后汇聚到听者耳朵的声线强度，在声线传播过程中考虑墙壁的吸收率和距离因素，通过声线强度估计场景的计算模型，使用生成的混响模型对声源的音频数据做混响处理，输出最终双耳音频。

物理模拟过程如下：

1. 以听者为中心，向四周随机且均匀地散射出 N 条声线，求得这些声线与场景的 N 个交点 $P_n, n \in (1, N)$
2. 计算出平均交点坐标 $\bar{P}$
3. 计算近似立方体房间
 - a. 计算出所有交点 P_n 到平均交点坐标 $\bar{P}$ 处的平均距离 $\bar{D}$
 - b. 假设立方体的边长为 $2\bar{D}$
4. 计算场景材质的平均声学参数。假设在上文提到的 N 个声线-场景交点 P_n 处，场景材质的吸收率是 A_n ，散射率是 S_n
 - a. 平均吸收率 $\bar{A} = \frac{\sum_{n=1}^N A_n}{N}$
 - b. 平均散射率 $\bar{S} = \frac{\sum_{n=1}^N S_n}{N}$
5. 利用估计的立方体房间，材质的平均吸收率，以及 Eyring 公式计算混响时长 T_{60}

当听者的位置发生变化时，从听者处发出的声线会相交于不同的场景物体表面，使得物理模拟过程所计算得到的混响时长 T_{60} 以及平均散射率 $\bar{S}$ 发生变化，以此进行动态混响的额计算。

动态可调的混响器结构如图 R.8：

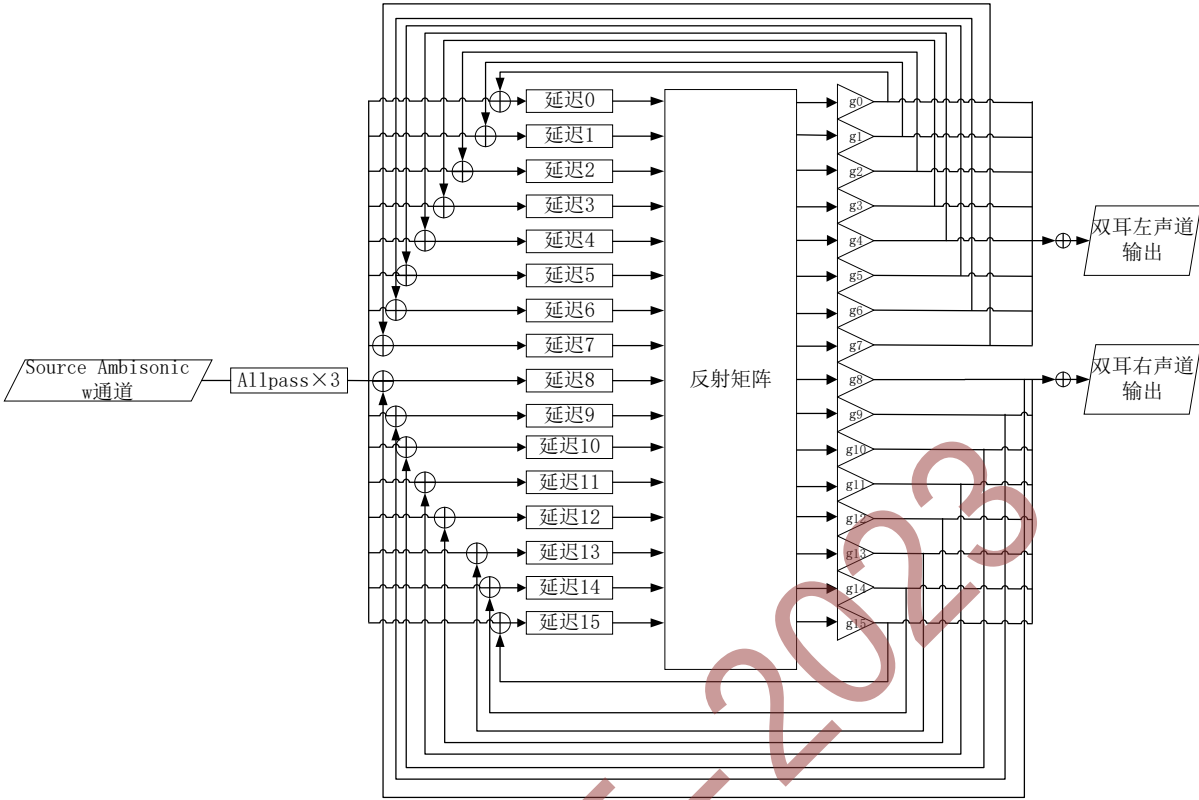


图 R. 8 动态可调的混响器结构

其中：

1. “Allpass x 3”使用的是三个级联的全通滤波器。
其中延迟时长是 5~10ms，且互为质数；滤波器延迟时长 g 受平均散射系数 $\bar{S}$ 控制
2. 延迟 0~15 的延迟时长是 30~50ms，且互为质数
3. 反射矩阵是 16 x 16 Householder 矩阵
4. $g_0 \sim g_{15}$ 是 15 个反馈增益，受混响时长 T_{60} 控制

附录 S
(资料性)
渲染器 ID2 的原理

S.1 对象音频的渲染

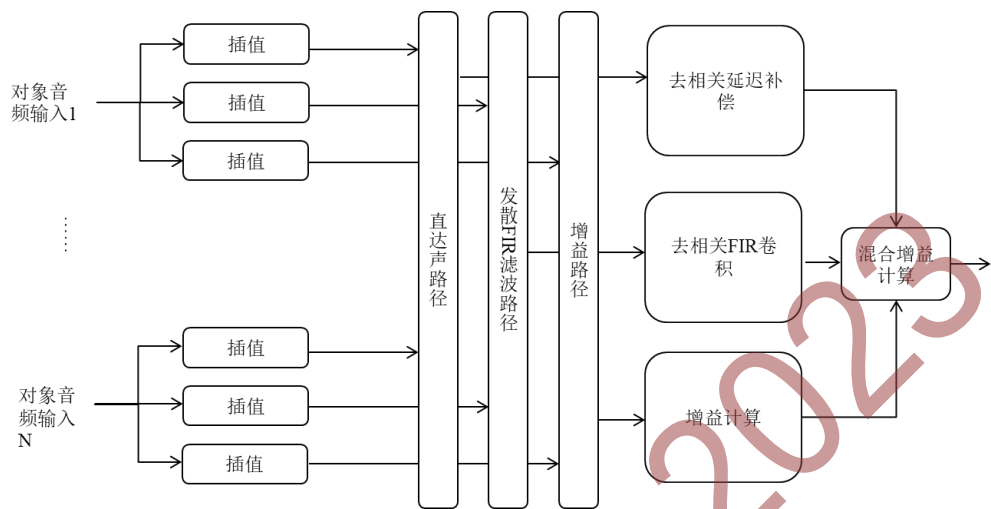


图 S.1 对象音频的渲染原理

对象音频的渲染原理如图S.1，对象插值分为三种处理：直达声的渲染、发散声的渲染（含卷积）和发散声相对于直达声延迟的补偿对齐。三种处理进行混合叠加后生成渲染输出。

渲染基于对象的音频，由音频类型判断（typeDefinition==Objects）提供元数据和音频数据的输入，元数据以ObjectsTypeMetadata进入渲染器，通过对元素元数据预处理模块的处理，经过objectsRender计算，获得基于对象内容的元数据和音频数据的输出。渲染内部处理过程如图S.2所示，ADM音频通过typeDefinition判断进入渲染器获得基于对象的元数据，通过元数据的加载可知该音频除direct直达声以外，是否存在diffuse发散声；随着音频信号的进入，元数据解析完成，将会加载音频前置增益、判断实际音频声道是否为lfe低频信号处理后，根据上述判断分别输入直达声路径和发散声路径进行增益计算；若直达声与发散声同时存在，则引入去相关延迟处理计算，使得两者时间对齐后混合渲染输出到目标扬声器。

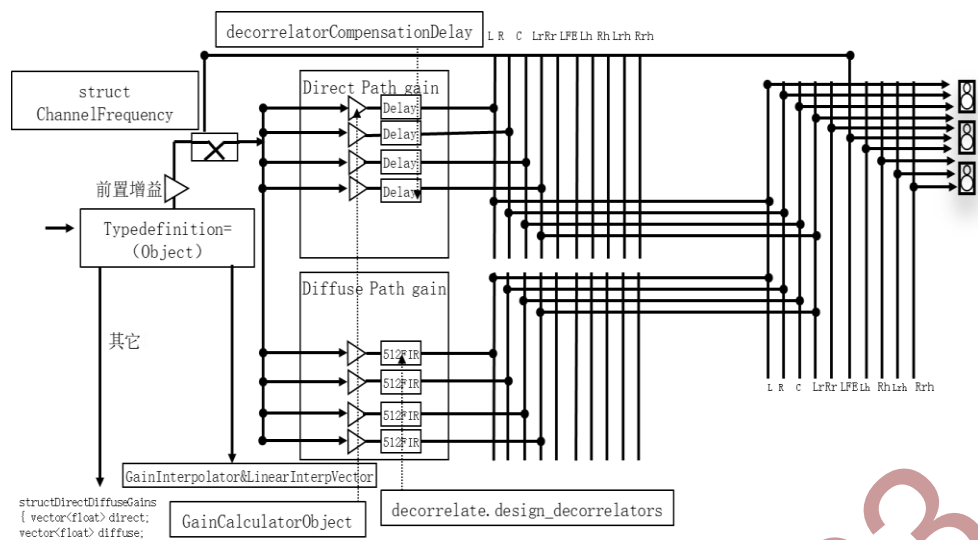


图 S.2 基于对象内容的元数据和音频数据的输出

图S.3是基于对象音频的渲染流程。渲染处理将分阶段进行：输入含元数据的音频后，渲染器首先判定坐标系，将球极坐标参数转换成元数据坐标系参数position或直接导入元数据坐标系参数position；当输入数据与屏幕相关时，将引入screenRef、screenEdgeLock、channelLock更新position参数，此更新将应用于重放环境的目标扬声器布局（n声道）；当应用objectDivergence发散时，对象音频可以分离扩展最多三个声像，此发散位置k将传输给点声源定位以计算面向目标扬声器布局的k×n增益矢量，经过功率总和后将每个扬声器的增益矢量总和一起；若引入zoneExclusion，则会排除设定区域的扬声器通道，产生新的增益矢量；增益适量经过增益计算获得每个扬声器通道的增益，通过分离输出直达声矢量和扩散矢量，以控制直达声和发散声的方向、路径。

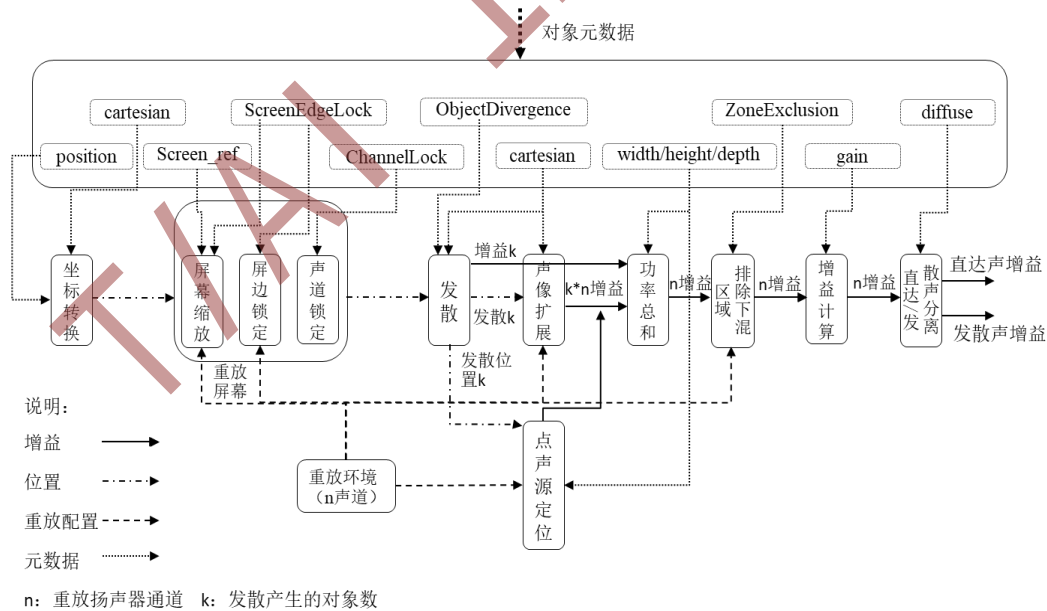


图 S.3 对象音频的渲染流程图

S.2 声道音频的渲染

声道音频的渲染原理如图 S.4:

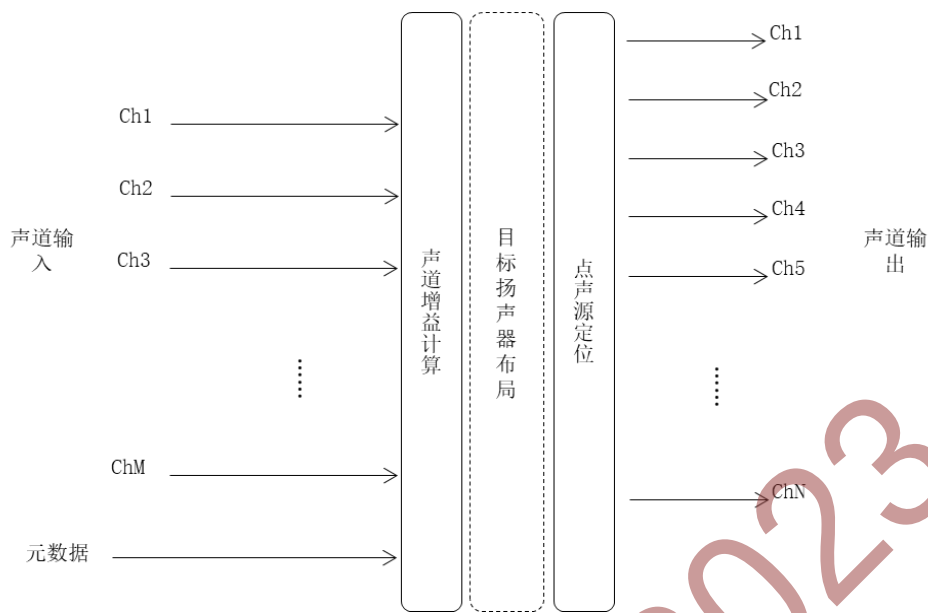


图 S.4 声道音频的渲染原理

使用声道增益计算器为声道计算的增益时，增益将直接应用在音频输入通道，直接生成输出音频频道。基于声道的元数据不应是动态的，因此增益不应在 `audioBlockFormat` 内插值，但如果用户更改元数据，则应插值增益。

增益计算时，输入的通道数与输出回放的扬声器布局通道数无关，无论输入通道数与输出通道数是否相等，渲染器按 BS.2051 的输出通道数进行渲染。当输入的 `DirectSpeaker` 数量少于输出的时候，会发生上混的增益计算，当输入的声道数量多于输出声道的时候，会计算出下混的增益。对于基于矩阵的音频类型，因矩阵音频类型基本信号为中间和侧面周围两个信号通道，故一般对侧面周围信号进行上混。在面向智能电视场景下的声道渲染方法可以根据家庭音箱布局采用增强环绕声的方法，见附录 I。

渲染基于声道的音频，由音频类型判断（`typeDefinition==DirectSpeakers`）提供元数据和音频数据的输入，元数据以 `DirectSpeakersTypeMetadata` 的形式进入渲染器；元素元数据预处理模块处理后，经过 `directspeakersRender` 计算，获得基于声道内容的元数据和音频数据的输出，如图 S.5 所示，ADM 音频通过 `typeDefinition` 判断进入渲染器获得基于声道类型的元数据，输入声道增益计算处理获得各声道增益，根据扬声器布局配置，通过点声源定位，将音频输出 `Pan` 至各扬声器通道。

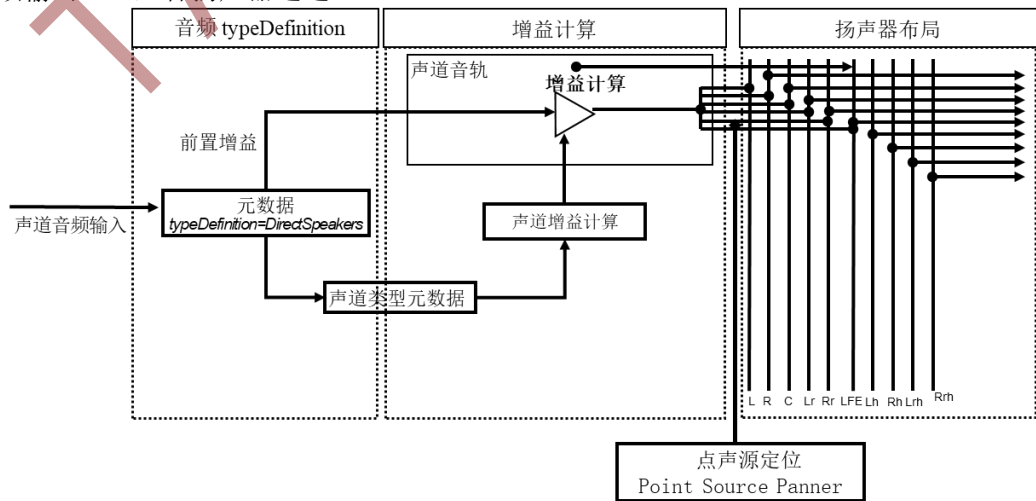


图 S.5 基于声道内容的元数据和音频数据的输出

S.3 HOA音频的渲染

HOA 音频的渲染原理如图 S.6, 基于 HOA 的渲染器选定 AllRAD 算法的 HOA 解码方法。通过 HOA 的解码器 D 计算出每一 HOA 轨道给每一个音箱的增益值 $HOA_{ns}pN_gain$; 将多轨 HOA 信号输出给独立的音箱。使用 GainCalculatorHOA 为 HOA 声道计算的解码矩阵 D 直接应用于输入音频信道, 以产生输出音频信道。与 DirectSpeakers 一样, HOA 元数据不应是动态的 (即每个 audioChannelFormat 中应有一个 audioBlockFormat), 因此增益不应在块内插值, 但如果用户更改元数据, 则应插值增益。在接口上显示之前, 调整接收信号的延迟 spN_delay , 使其与常规输出信号具有相同的延迟。

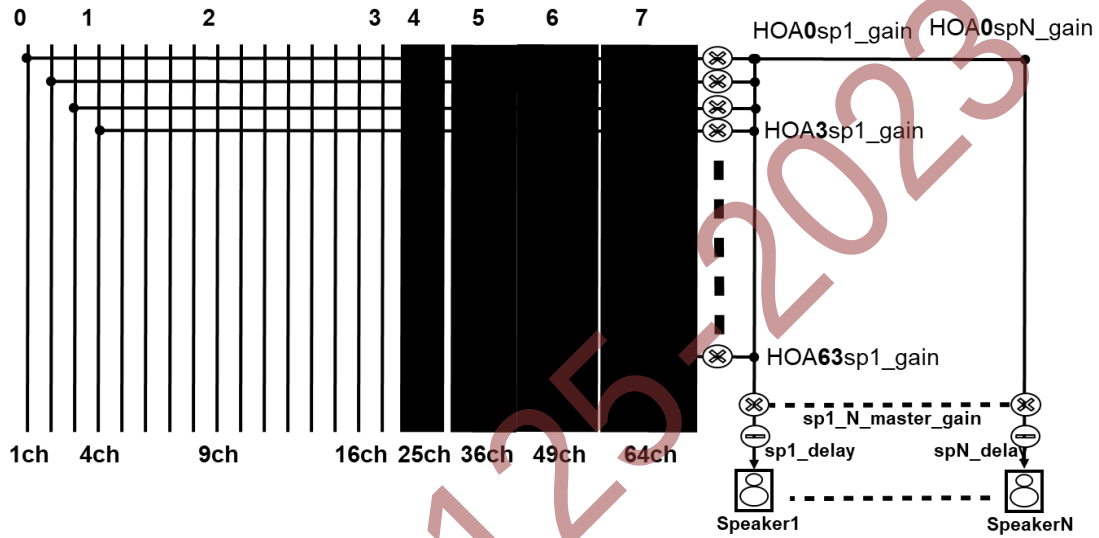


图 S.6 HOA 音频的渲染原理

AllRAD 算法通过解码器 D 描述了 Ambisonic 的增益 $g_{AllRAD}(\theta) = D_{y_N}(\theta)$, 解码器 D 的结果与 VBAP 的增益 $g_{VBAP}(\theta)$ 最为匹配。在没有最大重权的情况下, 基于 HOA 的渲染器通过该解码器 D 来定义 AllRAD, 该解码器 D 的积分用来表示所有方向 θ 上积分的最小均方误差问题:

$$\min_D \int_{S^2} \|g_{VBAP}(\theta) - D_{y_N}(\theta)\|^2 d\theta \quad \dots\dots (S.1)$$

当虚拟扬声器的最佳布局处采样的函数 $g_{AMBI}(\theta) = y_N(\theta) \text{diag}\{a_N\} y_N(\theta_s)$ 用作多个虚拟源输入时, 基于 HOA 的渲染器可以将 AllRAD 定义为物理扬声器上的 VBAP 合成, 这里, 可以把 VBAP 合成写成无穷多个虚拟扬声器 θ 上的积分:

$$\begin{aligned} g &= \int g_{VBAP}(\theta) g_{AMBI}(\theta) d\theta = \int g_{VBAP}(\theta) y_N(\theta) \text{diag}\{a_N\} y_N(\theta_s) d\theta \\ &= \underbrace{\int g_{VBAP}(\theta) y_N^T(\theta) d\theta}_{:=D} \text{diag}\{a_N\} y_N(\theta_s) \quad \dots\dots (S.2) \end{aligned}$$

从积分中提取项 $\text{diag}\{a_N\} y_N(\theta_s)$, 剩余的积分则定义了 AllRAD 的矩阵 D, 则可以将其认为 VBAP 扬声器增益函数 $g_{VBAP}(\theta)$ 到球极坐标系数的变换。此方法在不规则扬声器布局 (如 BS.2051 所述) 上可提供最为匹配的 HOA 解码。通过 AllRAD 的矩阵 D, 可将 HOA 信

号解码到均匀分布在球体上的虚拟扬声器，并能在实际扬声器上平移虚拟扬声器信号。

`allradDesign()` 全方向解码音频处理原理图如图S.7。在确定进行HOA渲染，渲染器将首先确定归一化配置（如：N3D）；解析确定归一化HOA元数据输入进`sphharm`处理，获得对应归一化的球面谐波分布值，次之为常数；分布值输入`calc_Y`处理获得HOA系数矩阵 Y_{virt} ，维度为：球谐分布值与对应归一化阶数的虚拟扬声器通道数值，并对 Y_{virt} 转置为 D_{virt} ；分布值另输入到`calc_G`处理，与配置的扬声器布局配置的通道数形成输出扬声器的定位矩阵 G_{virt} ，维度为：球谐分布值与对应目标扬声器布局的通道数值；进入`getHoaDecodeMatrix`矩阵相乘获得最佳HOA解码矩阵 $D=G_{virt} \times D_{virt}$ （此时 $G_{virt}=D_{virt}$ ）。

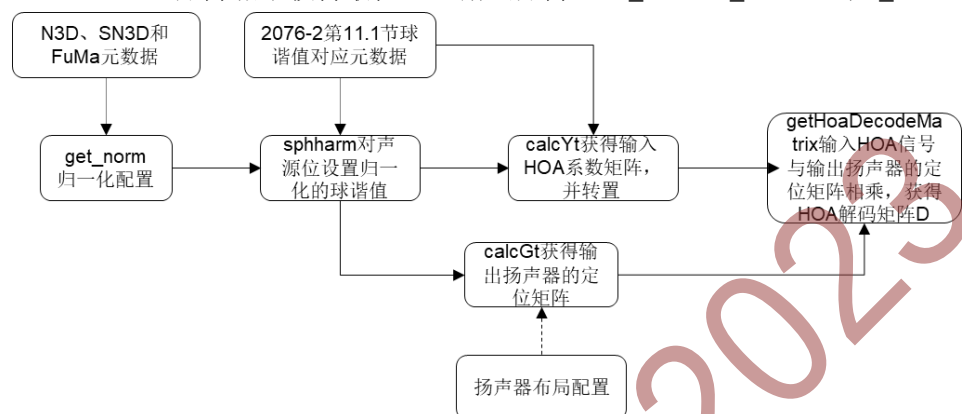


图 S.7 `allradDesign()` 全方向解码音频处理原理图

ADM 音频通过 `typeDefinition (typeDefinition=HOA)` 判断进入渲染器获得基于 HOA 的元数据，元数据以 `HOATypeMetadata` 的输入形式进入渲染器；接口设置为解码的 HOA 系数的元数据。

HOA 渲染器不支持除 HOA 外的其他音频元素的元数据。

10.11 和 10.12 节提供了此类接口的首选实现的语法和语义。实施者可以选择以不同的格式提供此优选实施中概述的信息，例如，使用不同的结构、不同的数据顺序。

基于非标准扬声器布局的渲染器参见附录O。

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