Furthermore, in general, attempting to reduce the computation amount leads to the potential problem of quality degradation.

[0032]

Embodiments of~~Thus,~~ the present invention ~~was conceived in view of the aforementioned problem and has as an object to~~ provide a bandwidth extension method capable of reducing the computation amount in bandwidth extension as well as suppressing quality deterioration in the extended bandwidth.

[Solution to Problem]

[0033]

Disclosed herein~~In order to achieve the aforementioned object, the bandwidth extension method according to an aspect of the present invention~~ is a bandwidth extension method for producing a full bandwidth signal from a low frequency bandwidth signal, the method including: a first transform step of transforming the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum; a pitch shift step of generating pitch-shifted signals by applying different shifting factors on the low frequency bandwidth signal; a high frequency generation step of generating a high frequency QMF spectrum by time-stretching the pitch-shifted signals in a QMF domain; a spectrum modification step of modifying the high frequency QMF spectrum to satisfy high frequency energy and tonality conditions; and a full bandwidth generation step of generating the full bandwidth signal by combining the modified high frequency QMF spectrum with the first low frequency QMF spectrum.

[0034]

Accordingly, the high frequency QMF spectrum is generated by time-stretching the pitch-shifted signals in the QMF domain. Therefore, it is possible to avoid the conventional complex processing (successively repeated FFTs and IFFTs, and subsequent QMF transform), for generating the high frequency QMF spectrum, and thus the computation amount can be reduced. Note that like STFT, the QMF transform itself provides joint time-frequency resolution, thus, QMF transform replaces the series of STFT and ISTFT. In addition, in the bandwidth extension method according to an embodiment~~aspect~~ of

coefficients corresponding to a temporally-extended audio signal.

[0041]

Specifically, the time stretching in the bandwidth extension method according to an embodiment~~aspect~~ of the present invention imitates the STFT-based stretching method by modifying phases of input QMF blocks and overlap-adding the modified QMF blocks with different hop size. From the point of view of computation amount, comparing to the successive FFTs and IFFTs in STFT-based method, such time stretching has a lower computation amount by involving only one QMF analysis transform only. Therefore, it is possible to further reduce the computation amount in bandwidth extension.

~~[0042]~~

~~Furthermore, in order to achieve the aforementioned object,~~ the bandwidth extension method in another aspect of the present invention is a bandwidth extension method for producing a full bandwidth signal from a low frequency bandwidth signal, the method including: a first transform step of transforming the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum; a low order harmonic patch generation step of generating a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain; a high frequency generation step of (i) generating signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generating a high frequency QMF spectrum from the signals; a spectrum modification step of modifying the high frequency QMF spectrum to satisfy high frequency energy and tonality conditions; and a full bandwidth generation step of generating the full bandwidth signal by combining the modified high frequency QMF ~~spectrum with the first low frequency QMF spectrum.~~

[0042]

According to a first aspect, there is provided a bandwidth extension method for producing a full bandwidth signal from a low frequency bandwidth signal, said method comprising:

a first transform step of transforming the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum;

a low order harmonic patch generation step of generating a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain;

a high frequency generation step of (i) generating signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generating a high frequency QMF spectrum from the signals;

a spectrum modification step of modifying the high frequency QMF spectrum to satisfy high frequency energy conditions; and

a full bandwidth generation step of generating the full bandwidth signal by combining the modified high frequency QMF spectrum with the first low frequency QMF spectrum.

[0042a]

According to a second aspect, there is provided a bandwidth extension apparatus that produces a full bandwidth signal from a low frequency bandwidth signal, said bandwidth extension apparatus comprising:

a first transform unit configured to transform the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum;

a low order harmonic patch generation unit configured to generate a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain;

a high frequency generation unit configured to (i) generate signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generate a high frequency QMF spectrum from the signals;

a spectrum modification unit configured to modify the high frequency QMF spectrum to satisfy high frequency energy conditions; and

a full bandwidth generation unit configured to generate the full bandwidth signal by combining the modified high frequency QMF spectrum with the first low frequency QMF spectrum.

[0042b]

According to a third aspect, there is provided a program for producing a full bandwidth signal from a low frequency bandwidth signal, said program causing a computer to execute:

a first transform step of transforming the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum;

a low order harmonic patch generation step of generating a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain;

a high frequency generation step of (i) generating signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generating a high frequency QMF spectrum from the signals;

a spectrum modification step of modifying the high frequency QMF spectrum to satisfy high frequency energy conditions; and

a full bandwidth generation step of generating the full bandwidth signal by combining the modified high frequency QMF spectrum with the first low frequency QMF spectrum.

[0042c]

According to a fourth aspect, there is provided an integrated circuit that produces a full bandwidth signal from a low frequency bandwidth signal, said integrated circuit comprising:

a first transform unit configured to transform the low frequency bandwidth signal into a quadrature mirror filter bank (QMF) domain to generate a first low frequency QMF spectrum;

a low order harmonic patch generation unit configured to generate a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain;

a high frequency generation unit configured to (i) generate signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generate a high frequency QMF spectrum from the signals;

a spectrum modification unit configured to modify the high frequency QMF spectrum to satisfy high frequency energy conditions; and

a full bandwidth generation unit configured to generate the full bandwidth signal by combining the modified high frequency QMF spectrum with the first low frequency QMF spectrum.

[0042d]

According to a fifth aspect, there is provided an audio decoding apparatus comprising:

a separation unit configured to separate a coded low frequency bandwidth signal from coded information;

a decoding unit configured to decode the coded low frequency bandwidth signal;

a transform unit configured to transform the low frequency bandwidth signal generated through the decoding by said decoding unit, into a quadrature mirror filter bank (QMF) domain to generate a low frequency QMF spectrum;

a low order harmonic patch generation unit configured to generate a low order harmonic patch by time-stretching the low frequency bandwidth signal in a QMF domain;

a high frequency generation unit configured to (i) generate signals that are pitch shifted, by applying different shift coefficients to the low order harmonic patch, and (ii) generate a high frequency QMF spectrum from the signals;

a spectrum modification unit configured to modify the high frequency QMF spectrum to satisfy high frequency energy conditions;

a full bandwidth generation unit configured to generate the full bandwidth signal by combining the modified high frequency QMF spectrum with the low frequency QMF spectrum; and

an inverse transform unit configured to transform the full bandwidth signal, from a quadrature mirror filter bank (QMF) domain signal to a time domain signal.

[0043]

Accordingly, the high frequency QMF spectrum is generated by time-stretching and pitch-shifting the low frequency bandwidth signal in the QMF domain. Therefore, it is possible to avoid the conventional complex processing (successively repeated FFTs and IFFTs, and subsequent QMF transform), for generating the high

Furthermore, the high order generation step includes: a splitting step of splitting each QMF subband in each of the bandpassed patches into multiple sub-subbands; a mapping step of mapping the sub-subbands to high frequency QMF subbands; and a combining step of combining results of the sub-subband mapping.

[0049]

Furthermore, the mapping step includes: a division step of dividing the sub-subbands of each of the QMF subbands into a stop band part and a pass band part; a frequency computation step of computing transposed center frequencies of the sub-subbands on the pass band part with patch order dependent factor; a first mapping step of mapping the sub-subbands on the pass band part into high frequency QMF subbands according to the center frequencies; and a second mapping step of mapping the sub-subbands on the stop band part into high frequency QMF subbands according to the sub-subbands of the pass band part.

[0050]

It should be noted that, in the bandwidth extension method according to the present invention, the process operations (steps) described above may be combined in any manner.

[0051]

Such a bandwidth extension method as that according to an embodiment of the present invention is a low computation amount HBE technology which uses a computation amount-reduced HF spectrum generator, which contributes the highest computation amount to HBE. To reduce the computation amount, in the bandwidth extension method according to an embodiment~~aspect~~ of the present invention, a new QMF-based phase vocoder that performs time stretching in QMF domain with a low computation amount is used. Furthermore, in the bandwidth extension method according to another embodiment~~aspect~~ of the present invention, to avoid the possible quality problems associated with the solution, a new pitch shifting algorithm is used that generates high order harmonic patches from low order patch in QMF domain.

[0052]

Embodiments of the present~~It is the object of this~~ invention disclose~~to design~~ a QMF-based patch

where time-stretching, or both time-stretching and frequency-extending can be performed in QMF domain, to make it further, to develop a low computation amount HBE technology driven by a QMF-based phase vocoder.

[0053]

It should be noted that embodiments of the present invention can be realized, not only as such a bandwidth extension method, but also as a bandwidth extension apparatus and an integrated circuit that extend the frequency bandwidth of an audio signal using the bandwidth extension method, as a program for causing a computer to extend a frequency bandwidth using the bandwidth extension method, and as a recording medium on which the program is recorded.

[Advantageous Effects of Invention]

[0054]

The bandwidth extension method in embodiments of the present invention designs a new harmonic bandwidth extension (HBE) technology. The core of the technology is to do time stretching or both time stretching and pitch shifting in QMF domain, rather than in traditional FFT domain and time domain, respectively. Comparing to the prior-art HBE technology, the bandwidth extension method in embodiments of the present invention can provide good sound quality and significantly reduce the computation amount.

[Brief Description of Drawings]

[0055]

[FIG. 1] FIG. 1 is a diagram showing an audio codec scheme using normal BWE technology.

[FIG. 2] FIG. 2 is a diagram showing a harmonic structure preserved HF spectrum generator.

[FIG. 3A] FIG. 3A is a diagram showing the principle of time stretching by respacing audio blocks.

[FIG. 3B] FIG. 3B is a diagram showing the principle of time stretching by respacing audio blocks.

[FIG. 4] FIG. 4 is a diagram showing QMF analysis and synthesis scheme.

[FIG. 5] FIG. 5 is a flowchart showing a bandwidth extension