analysis that is executed in the frequency spectrum analyzing unit in the pitch detecting apparatus of FIG. **1** in the case where an analysis length is equal to the odd number of samples;

FIG. **7** is a flowchart showing the frequency analyzing operation by MW-STFT which is executed in the frequency spectrum analyzing unit in the pitch detecting apparatus of FIG. **1**;

FIG. **8** is a diagram showing distributions on a frequency base and a time base of orthogonal function component waves in the frequency analyzing operation by MW-STFT that is executed in the frequency spectrum analyzing unit;

FIG. **9** is a flowchart showing a part of a pitch estimating operation of the independent type which is executed in a pitch estimating unit in the pitch detecting apparatus of FIG. **1**;

FIG. **10** is a flowchart showing another part of the pitch estimating operation of the independent type which is executed in the pitch estimating unit in the pitch detecting apparatus of FIG. **1**;

FIG. **11** shows spectrum diagrams for explaining operation and effect which are derived by a pitch estimating process according to the present invention; and

FIG. **12** is a flowchart showing the combination type pitch estimating operation performed in the frequency analyzing unit and pitch estimating unit in the pitch detecting apparatus of FIG. **1**.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Embodiments of the invention will now be described in detail hereinbelow on the basis of the drawings.

FIG. **1** shows an outline of a main construction (hardware) of a pitch detecting apparatus according to an embodiment to which the invention is applied.

In FIG. **1**, the pitch detecting apparatus has an electroacoustic transducer **1**, a frequency spectrum analyzing unit **2**, a pitch estimating unit **3**, and a storing unit **4**. The electroacoustic transducer **1** is an apparatus for converting input audio waves to an electric signal to output the signal, which is constructed by, for example, including a microphone. The conversion output signal (audio signal) of the electroacoustic transducer **1** is supplied to the frequency spectrum analyzing unit **2**. The spectrum analyzing unit **2** analyzes how the input audio signal includes orthogonal function components in accordance with a method, which will be explained hereinlater, namely, obtains an energy contribution degree information of the orthogonal components in the audio signal. The information obtained is sent to the pitch estimating unit **3** and each pitch is determined on the basis of the information. A determination result of the pitch is sent to the storing unit **4** and pitch information about all of the audio waves on the time base is accumulated. The frequency spectrum analyzing unit **2** and pitch estimating unit **3** don't need to show separated functional blocks. As shown by a broken line, each function can be also realized by a single block including both of them.

The pitch detecting apparatus constructed as mentioned above is suitable as not only a general frequency analyzing apparatus but also an apparatus for detecting a pitch of audio waves when it is used in wide fields such as audio recognizing apparatus, audio synthesizing apparatus, automatic score collecting apparatus, Karaoke grading apparatus, machine diagnosing apparatus, and the like.

The following two methods are mentioned as an operation principle of the frequency spectrum analyzing unit **2**.

(I) Method by an application of GHA (General Harmonic Analysis)

This method can be explained in accordance with a flowchart of FIG. **2**.

In FIG. **2**, the spectrum analyzing unit **2** executes processes (subroutine) of the flowchart in order to analyze frequencies of the input audio signal every observation interval L (analysis length) having a predetermined time width. The analyzing unit **2** first reads an audio signal $x_0(t)$ which occupies the observation interval L (step **S11**). In this reading process, discrete signals $x_0(k)$ {k=0, 1, 2, . . . } are obtained by sampling the original signal $x_0(t)$ at a predetermined sampling frequency fs. So long as the observation interval L corresponds to, for instance, a period of time of 512 samples, 512 discrete signals, whose sample numbers are k=0 to 511, are read. In the following description, it is assumed that L denotes the number of samples of 512.

The analyzing unit **2** subsequently substitutes **1** into a variable n, substitutes a value of L into a variable l, and further substitutes a value of l/n into a variable T (steps **S12**, **S13** and **S14**) and executes arithmetic operations for obtaining Fourier coefficients as shown in the following equations with respect to the predetermined values of n and T and the read signal $x_0(k)$ (step **S15**).

$$C_1 = \{2/(nT)\}\cdot\sum_{k=0}^{nT-1} x(k)\cos 2\pi k/T \quad (1)$$

$$S_1 = \{2/(nT)\}\cdot\sum_{k=0}^{nT-1} x(k)\sin 2\pi k/T \quad (2)$$

where, n and T are referred to FIG. **3**. Namely, n and nT are integers and denote the numbers of periods of a sine wave or a cosine wave as an orthogonal function component to be analyzed in the observation interval L. T indicates a value of the period of the wave. In the wave, the position (sample number) of k=0 in the observation interval L is set to a start point and the position (sample number) of k=nT−1 is set to an end point. In step **S15**, when n=1 and T=512, Fourier coefficients are obtained with respect to the component of waves forming one period for the observation period L as shown at the top stage in FIG. **3**.

After step **S15**,the analyzing unit **2** further executes an arithmetic operation to obtain Fourier coefficients as shown in the following equations (step **S16**).

$$C_2 = \{2/(nT)\}\cdot\sum_{k=L-nT}^{L-1} x(k)\cos 2\pi k/T \quad (3)$$

$$S_2 = \{2/(nT)\}\cdot\sum_{k=L-nT}^{L-1} x(k)\sin 2\pi k/T \quad (4)$$

They are referred to FIG. **4**. Although the values shown by n and T are equal, the Fourier coefficients are obtained with respect to the component of the wave in which the position of k=L−nT is set to the start position and the position of k=L−1 is set to the end position. In step **S16**, when n=1 and T=512, the Fourier coefficients are obtained with respect to the component of the wave forming one period for the observation period L as shown at the top stage in FIG. **4**.

The analyzing unit **2** subsequently averages the coefficients obtained in steps **S15** and **S16** (step **S17**). Arithmetic operational equations for averaging are as follows.

$$C=(1/2)\ \{C_1+\cos\ (\cos^{-1} C_2-\theta)\} \quad (5)$$