Mental Health Self-check System using "Lyspect"

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Abstract: The largest Lyapunov exponent (LLE) obtained through nonlinear analysis of plethysmograms contains information of the cerebral central system, which has been shown by mathematical model and experiments. Especially mental experiments have shown the significant relationship between LLE and mental status of an individual. The wave data are obtained by measuring changes in the blood flow of the capillary vessels of a fingertip, with an infrared sensor. Then the analogue format of the data is changed into digital format for calculation. Using "Lyspect" software, we next compute parameters including LLE, HF/LF, autonomic-nerve balance, and blood vessel age. These parameters, as functions of time, can be displayed in graphs. Notably, while the pulse wave is being measured, changes of LLE and HF/LF can be displayed in real time. Furthermore, the setup of measuring time and various parameters for calculation is available. The state at the time of the measurement can be studied by visualization. Additionally, the unsuitable wave data arising from the accuracy of the sensor and the external noise can be eliminated by the filter of Lyspect. Currently, a version of Lyspect that is installable on user-friendly smartphones is being developed, which will make even easier timely self-check of mental status.

1   INTRODUCTION

In chaotic datasets, attractor plots and "divergence" of attractor trajectories are characterized by Lyapunov exponents. Previously, we focused on the Lyapunov exponents of pulse waves in studying individuals in various situations (Imanishi and Oyama-Higa, 2006; Miao, Shimoyama and Oyama-Higa, 2006; Oyama-Higa and Miao, 2006; Oyama-Higa, Tsujino and Tanabiki, 2006). Our results showed that to maintain mental health, it is important for an individual to keep the harmony in the functioning of the sympathetic nervous system, which is associated the individual's qualities such as flexibility, spontaneity, cooperativeness, and the ability to interact with the external environment and society.

We also learned that the values representative of such harmony are associated with the largest Lyapunov exponent (LLE) obtained from nonlinear analysis (Oyama-Higa and Miao, 2005 and 2006). Essentially, in this research, LLE, which signifies temporal fluctuations in the attractor trajectory, is defined as "divergence". When this value is continuously low, namely, when there is no divergence for a long period, adaptability to external factors in daily life decreases, and thus mental health cannot be maintained. Conversely, a value that is continuously high for a long period represents a continued state of extreme anxiety or stress, and also mental health cannot be maintained in this case.

For humans, a healthy state can be defined as one in which high and low divergences constantly alternate. Normal human life includes a wide range of emotions, which is probably the cause of such changes in divergence. Using nonlinear analysis of pulse waves, an individual's mental health can be measured in approximately 1 minute, with the help of a low-cost pulse wave sensor. This offers the potential for easy assessment of mental health that can be performed regularly at home or workplace. We have created a trial version of the self-check system.

Mental health changes from day to day and hour to hour, so it is most important to monitor these fluctuations closely and intervene quickly when problematic symptoms emerge. To this end, we developed a self-check system producing a graph in which the degree of mental health over time is visualized as a constellation (Oyama-Higa et al., 2007).

"Lyspect" software can perform three types of

analysis (chaos analysis, blood-vessel balance analysis and autonomic-nerve balance analysis) using finger plethysmograms as input data. Besides the version that produces a detailed result for researchers, we also developed a simplified version of "Lyspect", called "Lyspecting", for general users.

2 MAIN FEATURES OF LYSPECT

Lyspect possesses the following functions.

2.1 Analysis

2.1.1 Chaos Analysis

To calculate LLE of pulse waves. Since Lyspect calculates the spectrum of Lyapunov exponents, values of Lyapunov exponents of all embedded dimensions are also found.

2.1.2 Blood-vessel Balance Analysis

To calculate blood-vessel balance equivalent to the estimated vascular age from a second differential wave pattern using Lyspect's own method.

2.1.3 Autonomic-nerve Balance Analysis

To calculate the LF and HF ratio from spectral analysis of variability in the HR cycle.

2.1.4 Others

It can also calculate the balance of sympathetic nerves and parasympathetic nerves using Lyspect's own method for estimating HF from heart rate transitions.

The analysis range and slide width for all analyses can be specified and adjusted. When the analysis range is shorter than the wave data length and the slide width is not 0, multiple results are generated by sliding along the analysis range for the amount of the slide width.

2.1.5 Pulse Wave Filtering (Optional)

To analyze pulse waves with a band-pass filter that removes bass-line transitions of wave data. It is available only when the filter option is installed.

2.2 Wave Input

Other than normal text files, Lyspect reads CCI's BACS-Advance binary wave data files as input wave data for analysis.

Another way is to dynamically read wave data from a connected cuff online.

Besides, it can also import wave data records from the DB of MSAS software, a self-check system using the database of the pulse waves which we have developed. In the case the DB contains records of analysis results, they are also imported and recorded as clips.

2.3 Analysis Result

There are two types of data to be saved.

1. Save analysis conditions and results to a file in CSV format, with each analysis on a single row.

2. Save sequences of analysis results in multiple rows to a file in CSV format when the slide width of the analysis is not 0 and multiple analysis results are generated.

2.4 Display and Save Pulse Waves

We introduce the following operations in Lyspect.

1. Save source data of displayed pulse waves to an external file in text format. This feature can be used, for example, to load and save BACS-Advance binary wave data.

2. Display a 3D Takens plot in chaos analysis. Assess the graph using zoom/pan.

Display Takens plot of wave data applied with a band-pass filter as source data. (Optional. Available only when the filter option is installed.)

3. Display second differential wave form of pulse waves (and markers indicating detected "a", "b" and "c" peaks). This wave data can be saved to an external file in text format.

4. Display a graph of heart-rate transition. This graph data can be saved to an external file in text format.

5. Display pulse waveform applied with a band-pass filter that removes transitions of original pulse wave data. (Optional. Available only when the filter option is installed.) This waveform data can be saved to an external file in text format.

6. Display waveform showing the bass-line transition. (Available only when the filter option is installed.)

This waveform is created simply by subtracting the pulse waveform that has been applied with a band-pass filter from the source pulse waveform.

The waveform data can be saved to an external file in text format.

3   HOW TO USE LYSPECT

Details on the usage of Lyspect are explained here in several steps.

3.1   Layout of the Operation Windows

The user can freely switch the layout of operation windows. Listed below are the main operation windows of Lyspect.

3.1.1   "Parameters"

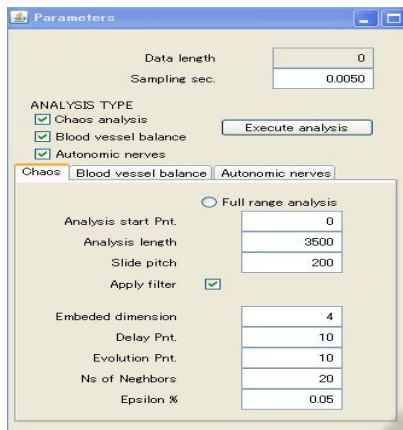In this window, analysis parameters are set.

Figure 1: Parameters.

3.1.2   "Wave Form"

In this window, the waveform of pulse waves is displayed.

Figure 2: Wave form.

3.1.3   "Resultgraph"

In this window, the analysis results are displayed using graphs.
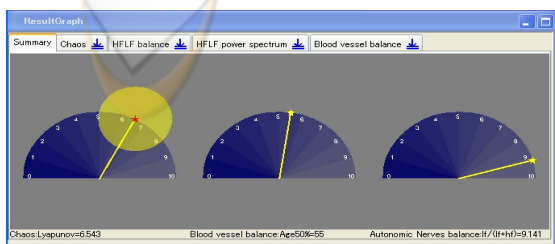
Figure 3: ResultGraph.

3.1.4   "ClipListTable"

In this window, a log of the analysis results is displayed in a table format.

Figure 4: ClipListTable.

3.1.5   "LogArea"

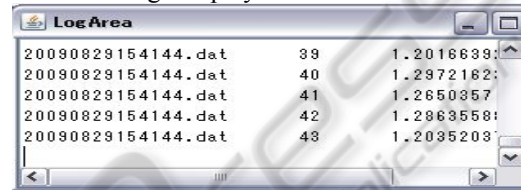This is a message display area for text information.

Figure 5: LogArea.

The above windows appear as sub-windows within the Lyspect main-window.

The layout is not fixed and can be freely moved by the user.

3.2   Loading Wave Data

There are mainly two ways to load wave data for analysis:

1.   Text files from a wave data file and BACS-Advance pulse wave binary files.

2. Loading wave data from a connected cuff. This operation loads data by sampling the wave data from a cuff connected to a USB port.

3.3   Setting Analysis Conditions and Analyzing

Analysis conditions are set in the "Parameters" window. See Figure 1.

Data length shows the number of sampling points of the loaded wave data.

In "Sampling sec.", the sampling rate is set. For example, we fill in 0.005 for 200Hz and 0.001 for 1,000Hz sampling rate.

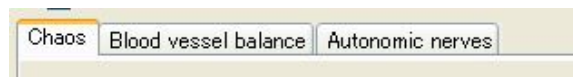There are three tabs that correspond to each type of analysis.

Figure 6: Three types of analysis.

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"Apply filter" is effective only when the band-pass filter is enabled. The feature is used to perform analysis of filtered data.

3.4 Graphical Display of Analysis Result
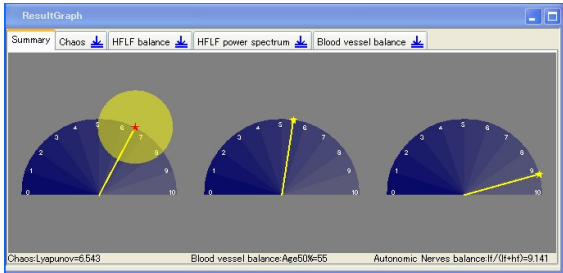
Analysis conditions are set in the "Parameters" window.

Figure 7: Summary.

There are a number of tabs on the top of the "ResultGraph" window.

3.4.1 "Summary"

This tab shows the main analysis result values of the three types of analyses in constellation graphs.

1. Chaos:
The average value of LLE in sliding analyses is shown as the angle of the meter and the standard deviation is shown as a circle where the radius is the standard deviation value.

2. Estimated vascular age:
The meter is in a range of 0 to 10 from which one obtain the estimated vascular age by multiplying the value with 10. For example, the value 3.2 means the age is 32.

3. Autonomic-nerve balance:
Autonomic-nerve balance is defined as the value of $LF / (LF + HF)$. A value larger than 5 indicates the sympathetic nerve dominance, namely, a state of stress, while a value smaller than 5 shows the parasympathetic nerve dominance, that is, a state of relaxation.

3.4.2 "Chaos"

This is a graph showing the changes of LLE resulting from sliding analyses where the number of slides is in the horizontal axis.
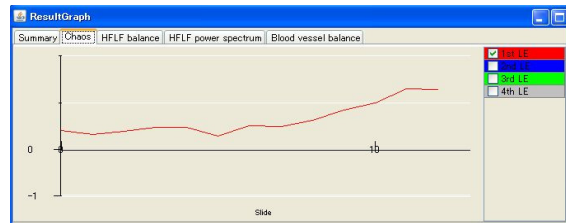

Figure 8: Chaos.

In Lyapunov analysis, the spectrum is found for the number of Lyapunov dimensions. But in the initial display, only the first Lyapunov exponent, namely the largest Lyapunov exponent (LLE), of the spectrum is displayed on the graph. Click the checkboxes of the legend on the right of the graph, and the second, third and fourth Lyapunov exponents will be displayed. The vertical axis of the graph is scaled automatically.

One is able to right-click the graph to save the graph data to an external file in CSV format.

If the chaos analysis is performed with Full range analysis or Slide pitch is 0, only one set of the Lyapunov spectrum will be calculated. In this case, the graph displayed in the "Chaos" tab will be a graph of the convergent calculation of the Lyapunov exponents as shown below.
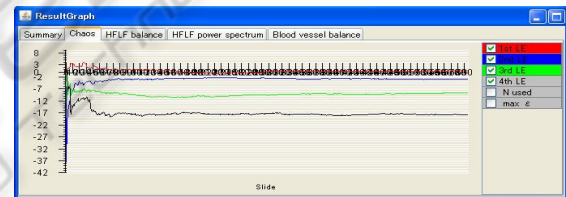

Figure 9: Display of four Lyapunov exponents.

3.4.3 "HFLF Balance"

A graph is displayed when one performs slide analysis by specifying the slide pitch rather than full-range analysis and setting the calculation method to HF-LF method in Autonomic-nerve balance analysis.
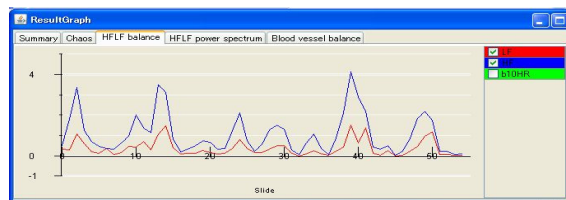

Figure 10: HFLF balance.

The graph shows changes of LF and HF values for the entire analysis area with the number of slides

in the horizontal axis.

In the case of slide analysis, the value of "b10HR" is calculated for the last analysis range (near the end of data).

Click the checkboxes of the legend on the right of the graph to enable/disable the display of HF, LF and "b10HR".

Right-click the graph to save the graph data to an external file in CSV format.

3.4.4 "HFLF Power Spectrum"

This spectrum distribution graph is displayed when the calculation method is set to HF-LF method in Autonomic-nerve balance analysis.
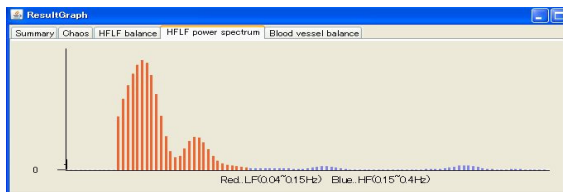

Figure 11: HFLF power spectrum.

The graph shows changes of LF and HF values for the entire analysis area with the number of slides in the horizontal axis.

In the case of slide analysis, the value of "b10HR" is calculated for the last analysis range (near the end of data).

Click the checkboxes of the legend on the right of the graph to enable/disable the display of HF, LF and "b10HR".

Right-click the graph to save the graph data to an external file in CSV format.

3.4.5 "Blood-vessel Balance"

This analysis evaluates suppleness of blood-vessel. One index value of suppleness is calculated from every time of pulsation, and shown in the graph.
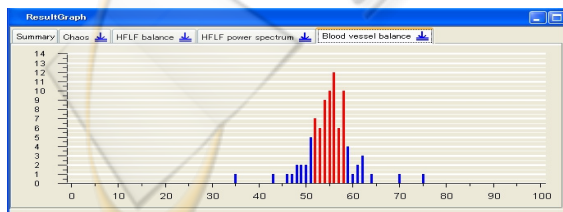

Figure 12: Blood vessel balance.

3.5 Numerical Display of Analysis Result

3.5.1 Clip and Clip List

The following is the "ClipListTable" window.

Figure 13: ClipListTable for analysis result.

A clip is a record of a single analysis:

Clip: = analysis data + analysis condition + analysis result (+ comment) (1)

A clip list is a set of clips. Normally, the list contains multiple clips.

Clip List: = clip + clip + ... + clip (2)

The clip list is displayed in the "ClipListTable" window in table format. In detail, a clip contains:

Wave data: = wave filename (3)

Analysis conditions: = parameters set in the "Parameters" window (4)

Analysis result: = analysis result for each of the three types of analyses including series of values such as chaos spectrum, HFLF power spectrum, etc. (5)

Comment: = any character string user entered. This item is completely optional, and used to enter information such as data profile or others. (6)

3.5.2 Setting the Items to Display in the "ClipListTable" Window

Since a clip contains enormous amount of numerical data, it is not advisable to display all numerical data in the "ClipListTable" screen.

The user may select the items to display in the window. To do so, select menu "Clip" and then "Clip table display columns" for details about the item names of analysis results.

3.5.3 Entering Comment

To enter comment, first select "Comments" as an item to display in the "ClipListTable" window. Next, click the "Comments" column of the row to enter

comment in the "ClipListTable" window. When the "EditText" window appears, enter or edit comment.

3.5.4 Displaying Graphics of a Clip

Clicking a clip in the "ClipListTable" window will display the following:

    1. The wave data of the clip in the "Waveform" window,

    2. The analysis conditions of the clip in the "Parameters" window and

    3. The graph of the clip's analysis result in the "ResultGraph" window.

3.5.5 Saving Clip List to a File

In Lyspect, saving analysis results is performed by saving Clip list to a file.

    Clip list may be saved by selecting "Clip" and then "Save file" in the menu. In order to prevent users from accidentally forgetting to save to a file, however, Lyspect will display a message asking "The clips have not been saved. Save?" when the user terminates it without saving Clip list.

3.5.6 Loading a Previous Analysis Result (Loading a Clip File)

A clip file can be loaded by selecting "Clip" and then "Read file" in the menu. The number of loaded clips will be displayed and Clip list will appear in the "ClipListTable" window.

    The last saved clip file can be loaded by selecting menu "Clip" and then "Read the last file". Lyspect saves the names of the last saved clip files and thus can load them quickly without finding their paths again.

3.5.7 Exporting Analysis Results in CSV Format

Although clip files are text files, the format is unique to Lyspect.

    In order to use the analysis results in other assessment applications such as MS EXCEL, clip information can be converted and saved in CSV format with commas separations.

    Each clip will be output in a single row.

    Since a clip contains enormous amount of data, information (columns) to output to a CSV file can be specified in the same way as specifying columns to display in the "ClipListTable" window.

    To save clip files in CSV format, select "Clip" and then "Export in CSV format" in the menu.

3.5.8 Deleting Clips from Clip List

To delete a clip from Clip list, click the clip to delete in the "ClipListTable" window, right-click to display the pop-up menu and then select "Delete". To delete all clips in Clip list, select "Clip" and then "Clear table" in the menu.

3.6 Displaying the Pulse Waveform

The "Wave form" window displays the wave data loaded from a file or a cuff. See Figure 2.

    The wave data displayed in the "Wave form" window is the pulse wave subject to analysis.

    The vertical axis of the wave graph is scaled so that the maximum value and minimum value of the entire wave data extend to the upper and lower edges of the graph.

3.6.1 Zooming the Waveform

Drag the mouse in upward direction on the graph to zoom in the horizontal axis of the waveform. In the same way, drag the mouse in downward direction to zoom out.

    To reset the scale, right-click on the mouse and then select the "Reset zoom" in the pop-up menu.
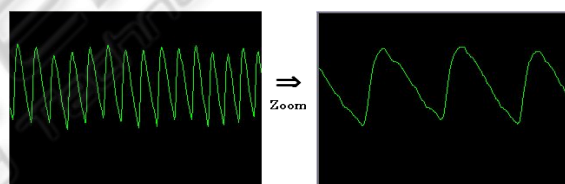

Figure 14: Zooming.

3.6.2 Displaying Secondary Pulse Waves

Waveforms generated by processing the source pulse waveform in various ways are called secondary pulse waves. These waves can be displayed by selecting menu "Display" and "Secondary waveform".

    To save secondary pulse wave data to an external file in text format, right-click on each graph and then select "Save wave file" in the pop-up menu.

3.6.3 Second Differential Waves

Second differential waves are waveforms that differentiate the source pulse waves twice and are used in analyses of both blood-vessel balance and autonomic-nerve balance since they effectively express the characteristics of pulse wave shapes.

Figure 15: Second differential waves.

"a", "b" and "c" peaks used for assessing the blood-vessel balance are drawn in white, red and blue lines respectively for each pulse wave.

3.6.4 Heart Rate Transitions

The "a" peak interval of the second differential waves refers to the pulse-cycle period and the heart-rate transitions graph shows the momentary heart rate found by inverse calculation of the pulse-cycle period.
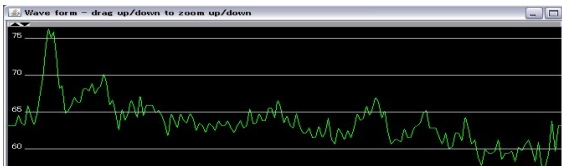

Figure 16: Heart rate transitions.

3.6.5 Band-pass Filter

This is available only when the filter option is installed.

3.6.6 Base Line Transitions

This is available only when the filter option is installed. The graph shows a waveform created by performing a simple subtraction of *original source waveform - filtered waveform*.
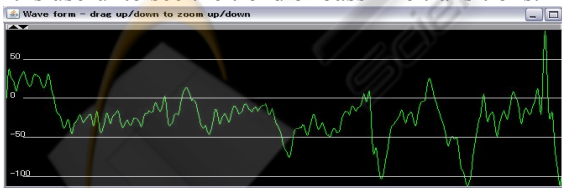It is useful to see the trend of bass-line transitions.

Figure 17: Base line transitions.

3.7 Chaos Analysis Takens Plot

The Takens plot of pulse waves can be displayed by selecting "Display" and then "Takens display" in the menu.
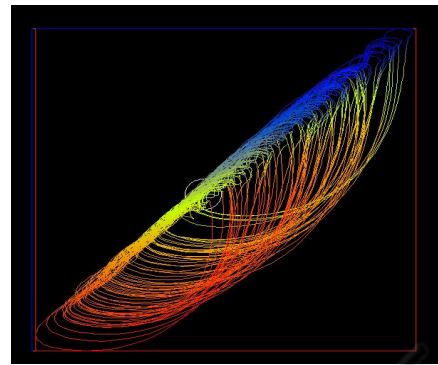

Figure 18: The Takens plot.

Although chaos analysis of pulse waves is performed in the embedded dimensions, the plot displayed here is a three dimensional plot.

The axis in depth direction is displayed using line colours. The red lines indicate at the front and blue lines indicate to the back. (All lines are displayed in green during in the initial state.)

Besides the source waveform, the filtered waveform can also be displayed when the filter option is installed.

As to the attractor displayed by the method of Takens, the following operations are possible:
1. Rotation of coordinates can be performed.
2. Zoom of coordinates is available.
3. Whether to display the sample point or not is optional.
4. The starting point of drawing and the number of the points of drawing can be set up.
5. Delay time and evolution time can be set up.

3.8 Names and Contents of Analysis Result Items

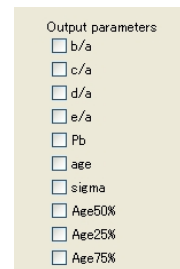### 3.8.1 Items Names and Contents of Blood-vessel Balance Analysis Result

Figure 19: Output parameters of blood-vessel balance analysis.

1. "b/a", "c/a", "d/a", and "e/a"

Average values for peak "a", "b", "c", "d" and "e" ratios for the entire analysis range. These are the bases for calculating the blood-vessel balance.

2. "Pb"

Estimation of the vascular age (method 1).

3. "age"

Estimation of the vascular age (method 2).

4. "sigma"

It denotes the vascular aging index σ.

5. "Age25%", " Age50% and "Age75%"

In contrast with "age" value, AgeXX% values are based on the distribultion graph of "age" values calculated from b/a, c/a, d/a and e/a of each pulse through the analysis area of pulse wave. Age25% is the value of "age" of one forth counting from smallest "age" value in the distribution graph, Age50% is the "age" value of the half counting in the graph, and Age75% is the "age" value of the three forth counting in the graph.

3.8.2 Item Names and Contents of Autonomic-nerve Balance Analysis Result
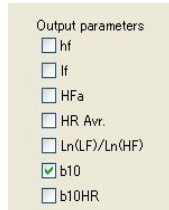

Figure 20: Output parameters of autonomic-nerve balance analysis.

1. "hf" and "lf"

They express each spectrum cumulative value, as the base of LF/HF spectral analysis. The balance of autonomic nerves is assessed by the ratio of HF and LF. LF is in the range of *0.04Hz – 0.15Hz*, while HF is in the range of *0.15Hz – 0.40Hz*.

2. "HFa"

It denotes the estimated HF found from the average heart rate. The formula is

$$HFa = K1 \times HR \times 3 + K2 \times HR \times 2 + K3 \times HR + K4, \quad (7)$$

$$0 \leq HFa \leq 100, \quad (8)$$

where *K1 to K4* are coefficients for approximation and HR is the average heart rate. These coefficients can be changed by selecting "System" and then "Configuration" in the menu.

A value taken between 40 and 60 indicates a normal balance. *HFa $\leq$ 40* and *60 $\leq$ HFa* indicate

sympathetic nerve dominance and parasympathetic nerve dominance, respectively.

3. "HR Avr"

It means the average heart rate within the analysis range

4. "Ln(LF)/Ln(HF)"

This parameter signifies the autonomic-nerve balance assessment value found from the log ratios of LF and HF. The formulas are:

$$B = Ln(LF) / Ln(HF), \quad (9)$$

$$B10 = B \times 10 / 3.5, \quad (10)$$

$$0 \leq B10 \leq 10. \quad (11)$$

B10 < 5 indicates parasympathetic nerve dominance, while *B10>5* indicates sympathetic nerve dominance.

5. "b10"

b10 shows the autonomic-nerve balance assessment value found from the ratios of LF and HF. The formulas are:

$$hflf = HF / (HF + LF), \quad (12)$$

$$b10 = (1 – hflf) \times 10 = LF / (HF + LF) \times 10, \quad (13)$$

$$0 \leq b10 \leq 10. \quad (14)$$

b10 < 5 indicates parasympathetic nerve dominance, while *b10>5* indicates sympathetic nerve dominance.

6. "b10HR"

It means the autonomic-nerve balance assessment value found from the HR value. The formulas are:

$$HFa = the\ HF\ value\ (\ \times 100\ )\ estimated\ from\ HR, \quad (15)$$

$$b10HR = (1 – Hfa / 100) \times 10, \quad (16)$$

$$0 \leq b10HR \leq 10. \quad (17)$$

b10HR < 5 indicates parasympathetic nerve dominance, while *b10HR > 5* indicates sympathetic nerve dominance.

4 EXAMPLES OF APPLICATION

We give three examples involving the calculation using Lyspect.

4.1 Example of a Healthy Subject

Below is a mentally healthy person's data. The subject is measured for three times, and for each time the duration of measurement is three minutes.

The blood vessel age of this subject is about 40 years.

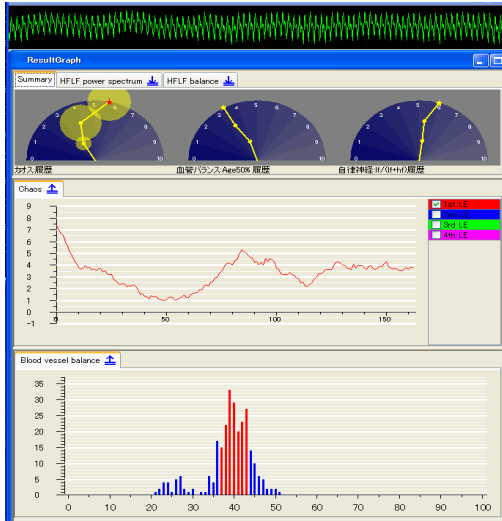LLE and autonomic-nerve balance are also in good condition.

Figure 21: ResultGraph of a middle-age healthy subject.

4.2 Example of an Elderly Subject

The subject is around 60 years old. From the three times of measurement, we found the LLE is low, but the autonomic-nerve balance is normal.
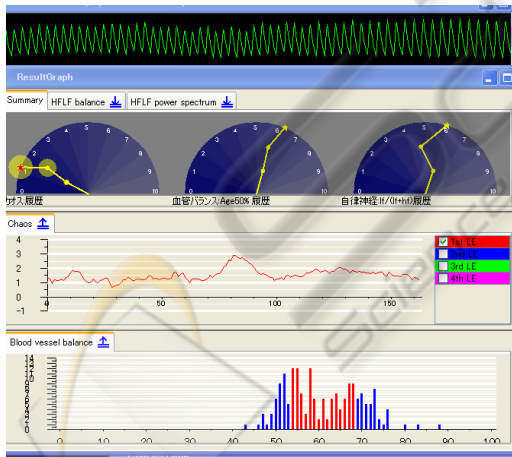

Figure 22: ResultGraph of an elderly healthy subject.

4.3 Example of a Depression Sufferer

In the following we present the result of a 49-year-old dysthymia-related obstacle (depression) sufferer. To increase the accuracy, we performed the measurement for 18 minutes in total. The result

shows that LLE is low and the value of autonomic-nerve balance is not less than 5 for each time. Thus the sympathetic nerve is higher in than parasympathetic nerve. This result agrees with the general tendency that the LLE of a mental disease sufferer is low and his or her autonomic-nerve balance is higher in than 5.
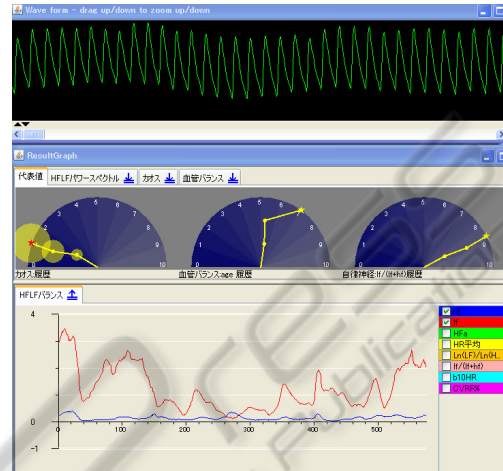

Figure 23: ResultGraph of a mentally ill subject.

5 DISCUSSION

With the help of Lyspect, individuals can perform self-checks and self-management for mental health. Mental health can be possibly maintained, if it is possible to ascertain exactly what kind of day-to-day conditions bring about high and low divergence. We are confident that even for those potential mental disease sufferers who regularly go to consult a counsellor or a psychiatrist, this system can aid in the early detection of depression or dementia, and thus prevent further deterioration of mental health.

Furthermore, we think it highly original to send and receive data related to mental health indicators across networks. However, it is essential to take great care in data management in light of confidentiality, which has become more important in recent years.

With the purpose of enabling users to perform the measurement at any time and anywhere as well as to compare their past health conditions on the Internet, we developed the software which can be used on the smart phone of Android loading . This software can also display the state of a pulse wave, LLE, autonomic-nerve balance, and blood vessel age. A measurement result can be saved via individual PC or the Internet with security management.

What is more, whenever necessary, the past measurement results can be retrieved from the database and investigated, and it therefore becomes possible to learn the change in one's mental state.

We expect that a small and cheap pulse wave sensor connectable with a mobile phone or a small PC will be developed early.

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