Health Information Services using Finger Plethysmogram

Mayumi Oyama-Higa[1], Tiejun Miao[2] and Shigeki Takada[3]
[1]Chaous Technology Research Lavolatory, 6-26-5 Seta, Otsu, Shiga, Japan
[2]TAOS Institute Inc, 1-7-8 kaigann,Minatoku, Tokyo, Japan
[3]Kwansei Gakuin University 1-1-155 Uegahara, Nishinomiya, Hyogo, Japan
mhiga@chaotech.org, info@itaos.org, takada@kwansei.ac.jp

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Abstract: The goal of this research is to develop a system that stores and displays visual analysis of measurements taken from pulse waves at the fingertip so that anyone can check their mental state including past information at any time and at any location. Furthermore, there is also the need to fully utilize the power of digital networks so that people and the people surrounding them are aware of such mental states.

1 INTRODUCTION

Up to now, it was said that living organisms must maintain homeostasis to maintain life. It was also thought that living organisms are capable of maintaining homeostasis due to the automatic control systems of the negative feedback mechanism. When applying vital signs that are directly associated with our lives such as the heart rate, respiration, blood pressure and body temperature to the concept of homeostasis, it can be said feedback is triggered to compensate any disturbance that causes certain values to deviate from their normal values, and the more stable these values are the more efficient the control systems of the living organism are functioning. But the heartbeat of a healthy person, for example, is never constant even if the person is in a relaxed state of mind. On the contrary, it fluctuates quite irregularly (heart rate variability). This also applies to the respiration, blood pressure, body temperature, etc. In fact, we know that there is less fluctuation of the heart rate among the elderly and individuals with medical conditions. The same can be observed in pulse waves. For this reason, there were continuous reports in the field of physiology around the mid-1980's indicating the possibility that such fluctuations including heart rate and brain waves are chaotic. Because no new knowledge could be gained when using the conventional method of linear analysis to analyze chaotic fluctuations, there was the need to analyze chaotic fluctuations using nonlinear methods. Recent advancements in computer processing speed and visualization capabilities have allowed us to analyze nonlinearly the chaotic properties of vital signs. Such technologies have opened new doors of understanding concerning information that was treated as error or simply unknown in the past to actually contain information that we wanted to know most.

Psychologists in the past have tried to examine the mental state of people through trial and error by asking a series of questions as there was no way to read a human mind. But if accurate information can be obtained by directly measuring vital signs and performing nonlinear analysis, such information should be greatly effective in the field of psychology that relies on the rules of thumb. Those involved in brain research conducted large-scale experiments such as directly inserting electrodes into the brain or taking video images based on the principle that all information can be found in the brain. However, we can now check with relative ease the various states of the mind by examining the pulse waves at the fingertip which contains information of the central nervous system. We are now able to assess the state of the sympathetic and parasympathetic nerves from pulse waves taken from finger plethysmogram. Combined with the information gained from nonlinear analysis of pulse waves we can also obtain other types information such as moods, etc. Such understanding was gained through many psychological and biological tests. In recent years, there has been an increase in the number of suicides

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resulting from depression as well as people causing social problems as the result of becoming mentally "high." What kind of mental state are they in? We believe that a measurement device that allows us to check the various mental states of ourselves would contribute, to a certain degree, a safer and peaceful society. We also believe the need to develop a system so that people can check themselves in order to handle major issues in the increasingly complex human society such as how to rejuvenate people mentally incapable of fitting into society in the aging society where one in every four will be 65 years old or older, how to detect and deal at an early stage the bullying of children that has become a serious problem of communal life, etc.

2 MEASUREMENT AND CHAOS ANALYSIS OF VITAL SIGNS

2.1 Vital Signs and Chaos

From the day we are born to the day we die, we humans continuously emit vital signs that fluctuate dynamically. Complex fluctuations are everywhere, including macroscopic fluctuations of life activities, the fluctuations of the heart and blood pressure, and the microscopic fluctuations on a molecular level. Such fluctuations, however, are neither constant fluctuations created mechanically nor fluctuations that are completely random. Living organisms fluctuate chaotically. Often times, chaos and random are interpreted to be the same. Unlike random, however, chaos has deterministic rules as shown in the diagram below. There are a number of ways to check whether a certain fluctuation is random or chaotic. One of these methods is to draw an attractor. Fig. 1 shows one of the methods for checking whether fluctuating data is random or chaotic. In the natural world, random and chaotic fluctuations exist outside constant, regular fluctuations. And it has already been established that pulse waves possess chaotic properties.

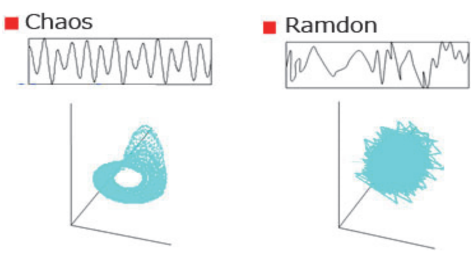


Figure 1: Difference between chaos and random shown using an attractor.

2.2 Measuring Pulse Waves from the Fingertip

As shown in Fig. 2, pulse waves from a finger is taken by measuring the increase and decrease of hemoglobin flowing through the capillaries at the fingertip using an infrared sensor and then converting the obtained analog information to digital data for use in calculation. Other than a fingertip, the sensor can also take measurements from an earlobe or even a toe. However, the sensitivity of the left-hand fingertip is especially suitable for measurement to synchronize with the blood flow from the heart.

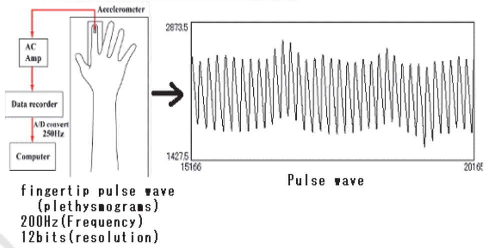


Figure 2: Measuring fingertip pulse waves.

2.3 Chaos Attractor and Analysis of LLE (Largest Lyapunov Exponent)

In order to create an attractor from fingertip pulse waves (hereafter just "pulse waves") , embedding dimensions d and delay time (time delayed for embedding) τ must be determined using Takens' embedding theorem. A good attractor cannot be drawn unless an appropriate value of τ is selected. If τ is too small, the value before delaying time τ and the value after delaying time τ will be almost the same, and the values will no longer be independent as the correlation is too strong. If τ is too large, phase relation information is lost as there will be no statistical correlation. Hence, there is the need to select the optimal delay time. Delay time is determined by continuously calculating nonlinear average mutual information (cross-correlation coefficient and delay time) to first find the smallest value of τ.

Next, embedding dimensions d is found by incrementally increasing the number of dimensions starting from two using the G-P algorithm (correlation dimension method) until number of correlations within the attractor stops increasing. The trajectories of an attractor fluctuate along with time. Such fluctuation is referred to as the largest Lyapunov exponent, or LLE. In our research, we conducted various psychological experiments by focusing our attention on the LLE. In order to assess what kind of information can be obtained from LLE, we created a mathematical model and conducted an experiment using general anesthesia. As a result, we were able to verify that LLE contains information of the central nervous system.

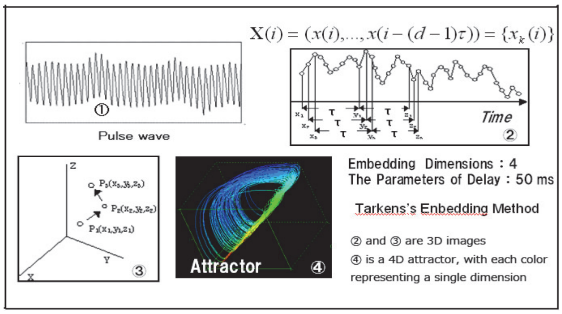


Figure 3: Method of creating an attractor from pulse wave data.

Fig. 4 shows the method for finding the largest Lyapunov exponent by calculating the fluctuations of the trajectories of an attractor over time.

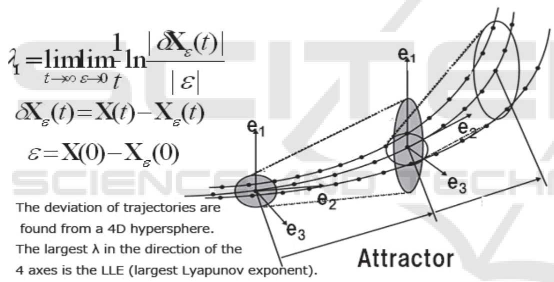


Figure 4: Finding the largest Lyapunov exponent (LLE).

The LLE representing the instability of trajectories of an attractor is found by calculating the LLE from the attractor structured by 3,500 points, delaying 200 points, calculating the LLE structured by the next set of 3,500 points and repeating the process until pulse wave data ends. 43 Lyapunov exponents are calculated from one minute of measurement data consisting of 12,000 points. One LLE is calculated in the first 17 seconds and then one every second thereafter. The average LLE found from the total time of measurement and standard deviation are used as assessment values in analysis.

2.4 Information That Can Be Acquired from Pulse Waves

We have discussed that LLE gain be obtained from nonlinear analysis of pulse waves. But there was also the need to check what that information was telling us. We conducted a simulation using a power spectrum by synthesizing waves that incorporate various conditions including blood pressure, heart rate and respiration transmitted from multiple parts obtained from the biological model shown in Fig. 5 and pulse waves. When running a simulation by entering formulas for the central nervous system, we found that the waveform of the mathematical model resembles the waveform created in the measurement test. This suggests that the mathematical model of pulse waves contain information of the central nervous system.

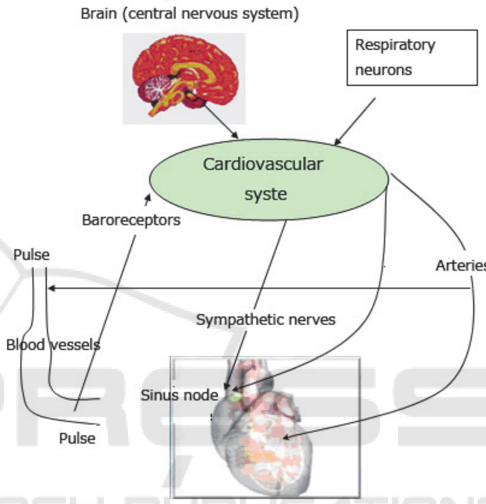


Figure 5: Mathematical model for simulating pulse waves.

The mathematical model was also verified in the experiment which examined the state of LLE during general anesthesia. If LLE contains information of the central nervous system, there should be a drop in the LLE when inducing general anesthesia. Fig. 6 shows the state of LLE during general anesthesia from the start to the end of surgery of a patient diagnosed with rectal cancer. Although the fluctuation of LLE does not drop to zero since the heart is moving, there is a gradual decrease in the LLE at the start of general anesthesia. During general anesthesia, LLE drops drastically. And upon recovery, LLE starts to rise again.

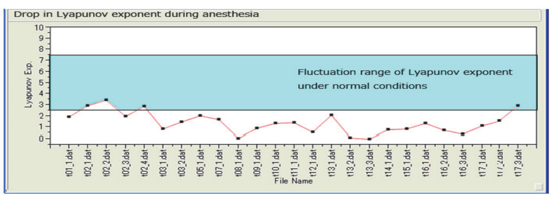


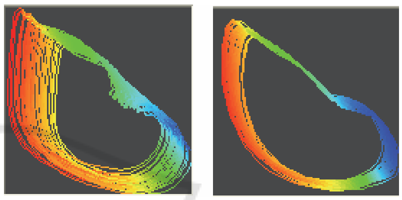
Figure 6: Changes in LLE during general anesthesia.

We were able to verify from the mathematical model and the general-anesthesia experiment that pulse waves are affected by the central nervous system.

3 RELATIONSHIP BETWEEN LLE AND COGNITIVE PSYCHOLOGY

Up to now, changes in the mental state of a human mind was never assessed numerically using biological information. Focusing on LLE obtained from nonlinear analysis of pulse waves, we conducted various experiments to study the relationship between LLE and dementia of the elderly, LLE and communication skills from view of the ADL index, LLE and error rate during work, LLE and daily variations of an employee as well as the cumulative fatigue index, LLE and changes in fluctuation over time between ages zero and five, LLE and the effects of a mother's affection on children, etc. The results have allowed us to gain understanding that LLE is closely associated with the things we humans need to maintain a healthy state of mind including external adaptation capabilities regarding the environment and society, flexibility of the mind, self-motivation and harmony. LLE that defines the fluctuation of the trajectories of an attractor can be defined as chaotic fluctuations. In other words, a continuously low LLE, or prolonged state without fluctuation, can be defined in everyday life as a drop in the power to adapt to the outside world. On the contrary, continuously high LLE and large fluctuation suggest continuous extreme tension or stress, preventing one from maintaining a healthy mental state. For human beings, a healthy state is a state with constant fluctuation. We also believe that human emotions cause change in the fluctuation. Let's look at a healthy mental state in contrast to physical immune strength. Normally, physical immune strength is said to be vital to maintain health. We human beings need physical immune strength to maintain our health. Drop in the immune strength can lead to various illnesses. In order to prevent this drop in physical immune strength (vitality), we eat carefully, rest, take medications and exercise to build up tolerance. On the other hand, what state defines the mind as healthy? Mental strength, such as the ability to communicate actively, motivation to live and the ability to tolerate the drastic changes in the outside world, is something extremely vital for the survival of mankind. If this is mental immune strength (vitality), there was no way to examine it using a scientific approach. Although mental immune strength is related to the vitality of human beings, it is basically a state of high or low and strong or weak. The mental immune strength is flexible and fluctuates constantly. A healthy state of mind is the ability to flexibly adapt to external changes with fluctuation. In other words, fluctuation of the LLE over time is critical to maintain mental health.

Fig. 7 shows an attractor of a mentally healthy person and an attractor of a depressed patient. Notice that the fluctuation of the attractor of the depressed patient is extremely small. Fig. 8 shows an attractor of a patient with dementia. Both attractors were drawn using data taken from an elderly. It is clear that the fluctuation decreases as the severity of dementia increases.



Attractor of healthy subject   Attractor of depressed patient

Figure 7: Attractors of a healthy person and a depressedpatient (30-second measurement).

Severity of dementia = 0   Severity of dementia = 4

Figure 8: Elderly data.

A continuously high state of LLE can also be observed during daily life when exposed to extreme tension or stress. A mentally healthy person can naturally relax after continuous exposure to extreme tension. This is because such person can lower the LLE to restore the fluctuation to a natural state. A person suffering from depression or an elderly with advanced dementia, on the other hand, will show a continuously low state of LLE. External adaptation is impossible in such state. In such case, there is the need for the person to examine his or her own changes in the LLE, learn from past states of LLE and allow the LLE to fluctuate by discovering methods that are effective or communicating with surrounding people. It is important to know yourself before proceeding with hospitals and medical treatment.

4 RELATIONSHIP BETWEEN LLE AND MENTAL HEARTH

4.1 Analyzing the Severity of Dementia and Communication Skills using Chaos Analysis of Pulse Waves Taken from the Elderly

Subjects: Measurements were taken from 179 patients (male: 40, female: 139) at three nursing homes in Shiga Prefecture.

Measurement period: August – November 2003.

Measurement method: Three measurements of three minutes each were taken using finger plethysmogram. Measurements were taken while maintaining the subjects in a relaxed state in a room set at 25°C. Prior to the measurement of pulse waves, the maximal blood pressure, minimal blood pressure, pulse and body temperature were taken.

Index: The relationship with LLE calculated from pulse waves was examined by utilizing data indicating the severity of dementia in five stages determined by a physician and ADL (3-level assessment) data consisting of seven items created by the care taker.

Results: Significant relationship was observed between LLE and severity of dementia, as well as between LLE and communication skills.

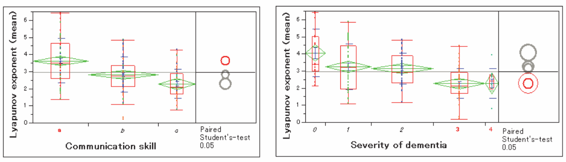


Figure 9: Relationship between LLE (vertical axis) and communication skills (left graph), and between LLE and severit of dementia (right graph). (Communication skills: 3 levels of a, b, and c; severity of dementia: 0 – 4).

The graph on the left shows significant drop in the LLE as the level of communication skills decreases. The graph on the right shows significant drop in the LLE as the severity of dementia progresses.

Fig. 10 shows the results of measurements taken nine months following the first set of measurements. Results varied from patients having higher LLE than the first time to those with less LLE. From the results, we were able to confirm that the value of LLE fluctuates constantly. However, the patient that passed prior to the second measurement had the lowest LLE among the patients during the first measurement. Is this an indication of something significant? The results are deeply concerning.

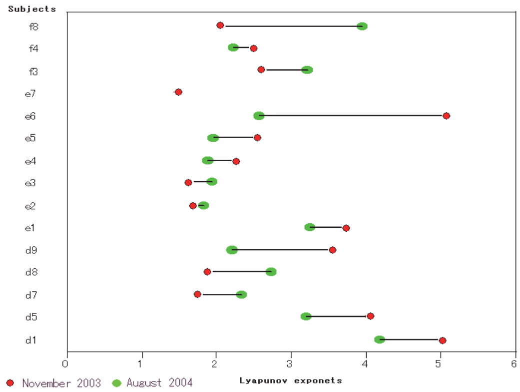


Figure 10: Results of LLE measurements taken nine months after.

4.2 Relationship between Changes in LLE of Children and the Mother's Affection

Subjects: 242 children between zero and five years of age at daycare centers in Osaka and Himeji.

Measurement period: January 2004 – March 2005.

Measurement method: Two measurements of a minute each were taken using finger plethysmogram. Measurements were taken while maintaining the subjects in a relaxed state in a room set at 25°C.

Results: The LLE of children between zero and five is lower at the age of three when compared to the other ages. The results of verification show a significant relationship with a probability of 0.05%.

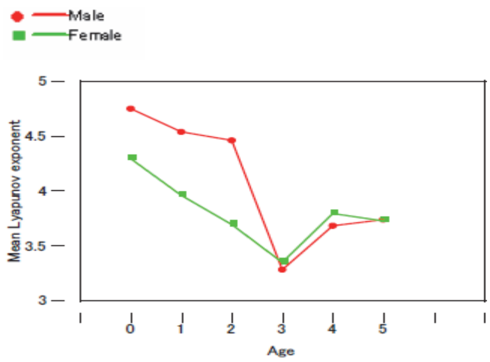


Figure 11: Changes in LLE of children by age (242 children).

The diagram show that the LLE is at its highest at the age of zero, followed by one and two, with three having the lowest value among all ages. The myth of the first three years has raised a question about the age of three as a global theme. It is highly significant that we were able to scientifically observe the trend using the LLE taken from pulse waves

4.3 Relationship between the Pulse Waves of Company Employees and the Fatigue Index

Depression among employees is becoming a social problem. We conducted an experiment examining the relationship between the LLE of company employees during the day and the fatigue index. From the fatigue index obtained through a series of questions, we were able to conclude that the drop in LLE was caused by "depressive state" and "anxiety." The results are shown in Table 1. Note that "anxiety" and "depressive state" show a negative correlation of -0.7 or higher when compared to the LLE during work. In other words, low LLE during work suggests a depressive state or high anxiety.

Table 1: Relationship between LLE of employees during the day and the fatigue index.

	Drop in willpower	Degree of anxiety	Depressive state	Accumulation of fatigue	Lyapunov exponent during the day
Drop in willpower		0.7235	0.7539	0.7496	-0.6385
Degree of anxiety	0.7235		0.8455	0.9358	-0.7279
Depressive state	0.7539	0.8455		0.842	-0.7279
Accumulation of fatigue	0.7496	0.9358	0.842		-0.6305
Lyapunov exponent during the day	-0.6385	-0.7279	-0.7014	-0.6305	

4.4 Relationship between LLE and Judgment and Operational Errors during Monitoring Work

In order to conduct an experiment on human error, we developed a device that creates a virtual environment for performing monitoring work on a computer. In this experiment, we examined the relationship between LLE and the error rate. The results showed the low LLE causes an increase in the error rate.

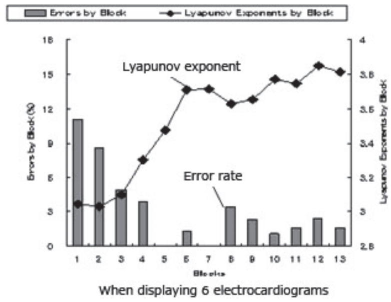


Figure 12: Relationship between LLE during monitoring work and error rate.

4.5 Changes in LLE When Giving Birth

Fig. 13 shows the results of examining the changes in LLE of seven pregnant women before and after giving birth (maternity clinic in Nara-shi). The LLE within 90 minutes of giving birth and the LLE within 90 minutes after giving birth were compared. The LLE prior to giving birth is significantly high

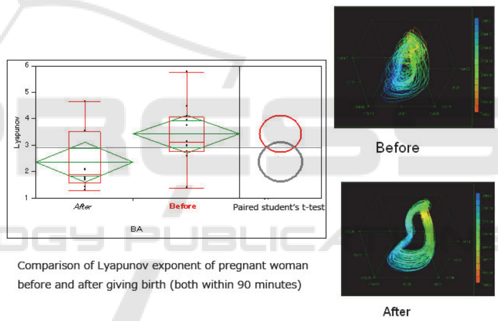


Figure 13: Comparison of LLE before and after giving birth (both within 90 minutes).

4.6 Relationship between LLE and Laughter

It is often said that laughter is the best medicine. The diagram below shows the changes in LLE when watching and not watching a comedy video for five minutes.

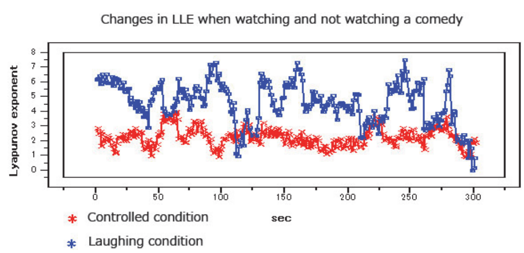


Figure 14: Changes in LLE when watching and not watching a comedy video.

From the various examples we have observed, we can summarize the LLE of a mentally healthy person as follows:

- The LLE of a mentally healthy person fluctuates constantly within a certain range. Furthermore, the LLE changes unconsciously.
- The LLE of a person suffering from depression or dementia is continuously low.
- Continuously high LLE indicates extreme tension and stress, and at risk of losing mental balance.

From the above, we can say that the mental state cannot be determined with single measurement of LLE.

5 NECESSITY OF SELF-CHECK SYSTEM FOR MENTAL HEALTH

5.1 Social Needs and Cautions concerning Measurements

There are said to be more than 30,000 suicides per year in Japan. Although depression is not the only cause, depression is often times accompanied by an alternating cycle between depressive state and manic state. Severe manic state triggered by medication is said to be a cause for suicides. We believe that knowing your own state by measuring pulse waves as a means of self-control can be effective in preventing suicides.

We know that Japan is on the way to an aging society, where one in every four persons will be 65 years old or older in 2025. Some of the issues of aging are enormous medical costs and nursing costs that ultimately affect the lifestyles of individuals. What can we do to keep working energetically even when we age, or to make sure we do not put a burden on our family with dementia? These are all issues that we must take seriously. Currently, we are examining the effects that animal-assisted therapy, music therapy and life review have on communication and motor skills. We are also conducting experiments on LLE to see which methods are effective for rejuvenating the elderly. However, methods for improving the LLE will differ for each individual. But everyone is capable of improving their LLE. We believe that it is up to the individual to discover the best method.

Judging from the above, we decided the need to develop a self-check system so that anyone can measure their LLE at any time and at any location. We developed a software program called Lyspect that measures not only the LLE from the pulse waves measured at the fingertip, but the state of sympathetic nerves, parasympathetic nerves and autonomic nerves, and the health of blood vessels. But in order to check past measurement records and to check your mental state based on the feedback of such information, there is the need for a database and the use of the Internet.

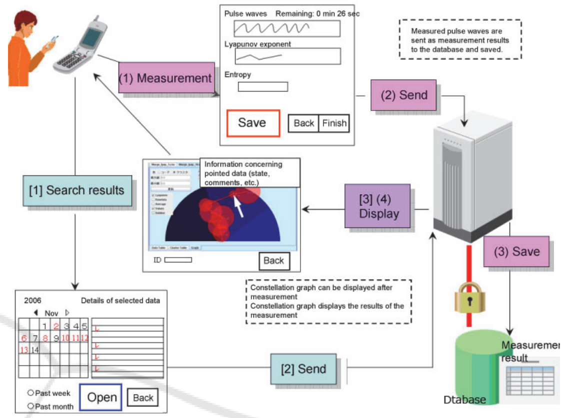


Figure 15: Image of performing finger plethysmogram using a cell phone or smartphone, performing nonlinear analysis to calculate biological information such as the LLE, and saving the data in database and loading past records.

6 INTRODUCTION OF LYSPECT

We developed a software program capable of calculating and displaying the following by measuring pulse waves. Lyspect is capable of analyzing and display the three types of values with pulse waves as input data.

Chaos analysis (calculation of LLE), vascular balance analysis, autonomic nerve balance analysis. The program is also capable of displaying LLE and HF/LF in real time by connecting a sensor.

There are two types of Lyspect: the original Lyspect that can be used for research and Lyspecting, a simple version of the original.

Fig. 16 shows the results of five measurements taken from a single person using Lyspecting, the simpler of the two.

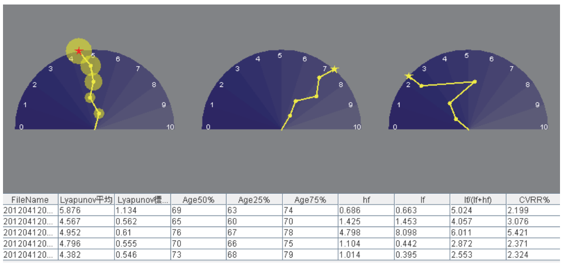


Figure 16: Results displayed by Lespecting (5 measurements).

Fig. 17 shows the results of three measurements taken from a depressive patient. The LLE is constantly low and the autonomic nerve balance indicates that the sympathetic nerves are superior.

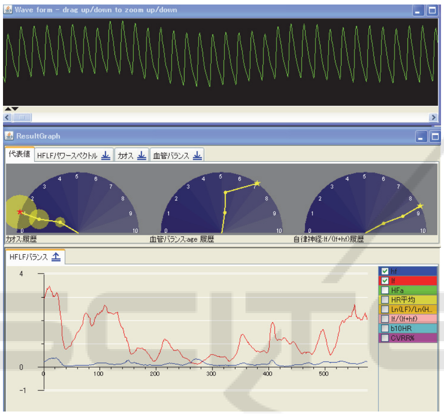


Figure 17: Results of depressive patient displayed by Lyspect.

We have also developed a software program that can be operated on android smartphones.

7 INTRODUCTION OF LYSPECT

We verified the deep relationship between human emotions and LLE calculated based on nonlinear analysis of the micro-fluctuations in pulse waves that contain chaotic properties by creating mathematical models and conducting experiments using general anesthesia. We have also developed a software program for analysis. Our challenge for the future is to develop a pulse wave sensor that any can easily use and afford. In order obtain data using a cell phone or smartphone, there is the need for the sensor to be small and light. Although we have succeeded in realizing a wireless and USB connection, we are requesting others to develop a sensor that is compact and user friendly.

There is also the need to address security issues as biological information is handled. We believe we can resolve this issue by selecting the appropriate database management method and communication method.

REFERENCES

Moore, R., Lopes, J., 1999. Paper templates. In *TEMPLATE'06, 1st International Conference on Template Production*. SciTePress.

Smith, J., 1998. *The book*, The publishing company. London, 2nd edition.

Tsuda I., Tahara T., Iwanaga I., 1992. Chaotic pulsation in capillary vessels and its dependence on mental and physical conditions. Int J Bifurcation and Chaos 2: 313-324.

Sumida T., Arimitu Y., Tahara T., Iwanaga H., 2000. Mental conditions reflected by the chaos of pulsation in capillary vessels. Int J Bifurcation and Chaos 10: 2245-2255.

Sano M., Sawada Y., 1985. Measurement of the Lyapunov spectrum from a chaotic time series. Phys. Rev. Lett. 55: 1082.

Abarbanel HDI., Brown R., Sidorowich JJ., Tsimring LS., The analysis of observed chaotic data in physical systems. Rev Mod Phys 1993., 65: 1331-1392.

Tokihiko Niwa, Kenji Fujikawa, Yoshikazu,Tanaka, Mayumi Oyama, 2001. Visual Data Mining Using a Constellation Graph, ECML/PKDD-2001, Springer-Verlag. (Academic Journal, 2001.) Working Notes/29-44.

Oyama-Higa M., Miao T., Mizuno-Matsumoto Y., 2006., Analysis of dementia in aged subjects through chaos analysis of fingertip pulsewaves. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2863–2867.

Takens F., In: Braaksma B. L. J., Broer H. W., Takens F., eds. 1985. Dynamical Systems and Bifurcations, Lecture Notes in Math. Vol. 1125. Springer, Heidelberg.

Miao T., Shimoyama O., Oyama-Higa M., 2006. Modelling plethysmogram dynamics based on baroreflex under higher cerebral influences. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2868–2873.

Oyama-Higa M., Miao T., 2006. Discovery and application of new index for cognitive psychology. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2040–2044.

Imanishi A., Oyama-Higa M., 2006. The relation between observers' psychophysiological conditions and human errors during monitoring task. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2035–2039.