A Mental Health Self-Check System using Nonlinear Analysis of Pulse Waves

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Abstract— **Previously, we demonstrated that simple, low-cost measurement of an individual's mental health is possible using nonlinear analysis of pulse waves. Here we introduce a trial system that records and assesses the relationship between mental health and lifestyle habits. Our goal was to develop a system that allows individuals to decide which steps to take for recovery when they develop worrying mental health symptoms, by making comparisons to their past lifestyle habits. This system also allows records of multiple individuals to be entered into a database and analyzed. Such analysis should allow for the creation of indicators for general levels of mental health that may require intervention, as well as the creation of more concrete, practical advice to aid recovery when worrying symptoms appear.**

Keywords—**pulse wave, non-linear analysis, Lyapunov exponent, divergence, mental health, pulse wave mouse, constellation graph, time series**

I. INTRODUCTION

In chaotic datasets, attractor plots and 'divergence' of attractor trajectories are characterized by Lyapunov exponents. Previously, we focused on the Lyapunov exponent of pulse waves in research targeting persons of various ages and in various situations [1-4]. Our results showed that to maintain mental health, it is important that there is harmony with the appropriate functioning of the sympathetic nervous system, which is associated with qualities such as the ability to interact with the external environment and society, flexibility, spontaneity, and cooperation. We also learned that the values

representative of such harmony were associated with the maximum Lyapunov exponent (MLE) obtained from nonlinear analysis [5,6]. Essentially, in this research, the MLE, which signifies temporal fluctuations in the attractor trajectory, is defined as 'divergence', and while this value is continuously low, i.e., while there is no divergence for a long period, adaptability to external factors in daily life decreases, and 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 again mental health cannot be maintained. For humans, a healthy state can be defined as one in which high and low divergence constantly alternate. Normal human life includes a wide range of emotions, and it is likely that this is exactly what causes changes in divergence.

Using nonlinear analysis of pulse waves, an individual's mental health can be measured in ~1 minute, i.e., the time it takes to perform a pulse-wave measurement, using a low-cost pulse-wave sensor. This offers the potential for mental health to be easily measured every day in the home or at work.

We created a trial version of our system using an easy-to-use self-check system to regularly assess mental health at home or in the workplace, and to record these measurements in combination with responses to questions on lifestyle habits.

Mental health changes from day to day and hour to hour, and it is most important to monitor these fluctuations closely and intervene quickly when problematic symptoms emerge. To this end, we proposed a self-check system using a graph in

which the degree of mental health over time is visualized as a constellation [7]. The system we developed was designed so that changes could be tracked on the Mental Stress Analytical System (MSAS) from four perspectives, using constellation graphs and questionnaire records linked to pulse-wave data. In addition, because the system is intended for use by non-specialists, it was designed so that a new user can use it at a basic level, and then perform familiarization tasks directly as necessary.

II. SYSTEM

A. Overall Configuration

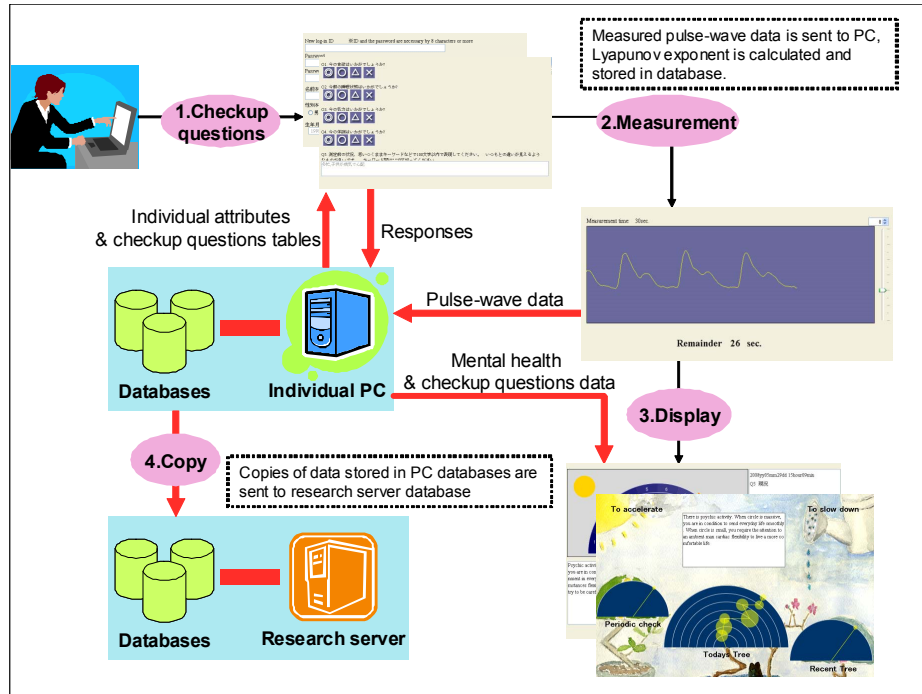Fig. 1 shows the overall configuration of the trial MSAS.

Figure 1. Overall configuration of the MSAS

The configuration is explained below in terms of the data flow.

1. When starting the MSAS, a questionnaire specification preloaded on the personal computer (PC) database is sent to the PC, and based on this specification, users are asked questions about their individual attributes, and every time a pulse-wave measurement is taken, they are asked check-up questions. The answers are stored in the PC database. The questionnaire can be designed for a sample population, such as the elderly or a specific company.

2. Pulse-wave measurement data are stored in the PC database in advance, and pulse-wave measurements from a mouse with a pulse-wave sensor attached are sent to the PC. The PC calculates the Lyapunov exponent value indicative of mental health from the pulse-wave data and, together with the pulse-wave measurement information, sends this to the database where both are stored.

3. The check-up questions data stored on the internal PC database and the mental health calculation obtained simultaneously are both displayed on the PC as constellation graphs showing time series data from three perspectives. Users can also combine and display data freely. Looking at this display, users can check for any worrying symptoms related to mental health and can plan their own recovery based on changes in data on past check-up questions. In addition, with this trial MSAS, the assessment of changes in mental health can be used to derive basic advice on self-recovery methods for the general population.

4. Copies of the data in each database are sent to a research server database and stored. The research database will accumulate data sent from researchers all over the country, and analysis of these data should enable the creation of indicators for the level of general mental health that may require intervention, as well as the creation of more specific, practical advice to aid recovery when worrying symptoms appear.

Although the trial version uses the configuration described above, it can also be implemented as a self-contained PC model without sending duplicate data to the research database, or as an internet-based model that uses a server database directly, instead of a PC database. A mobile phone or specialist device could be used instead of a PC, and in anticipation of this, the software was written mainly in Java and designed to be highly adaptable to cross-platform migration.
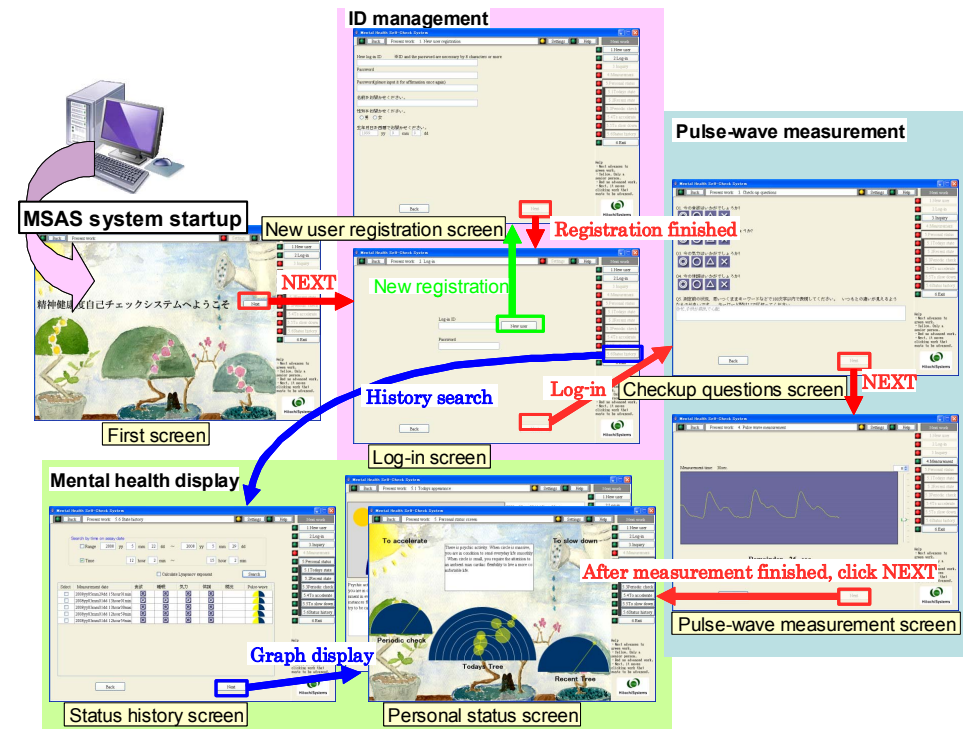
B. Flow of the MSAS system use

Figure 2.   Overview of the MSAS system use from the user's viewpoint, excluding research workflow

Fig. 2 shows the steps followed by a first-time system user. Since the NEXT button can be clicked to proceed when a process has finished, the design allows a first-time user to work through the screens simply by pressing NEXT. With increased familiarity, the user can use short-cuts by selecting green items on the menu at the right of each screen to jump to a new screen directly.

1.   As indicated by the red lines in Fig. 2, after starting the CGR and entering the user ID and password, the check-up questions screen appears, and the user's current physical condition or worries can be recorded. Then, the pulse-wave is measured. When a normal pulse-wave is not measured, such as when the finger moves, a request to repeat the measurement appears during the measurement process.

2.   After the measurement is completed satisfactorily, pressing NEXT brings up the mental health self-check screen. A detailed view of this screen is shown in Fig. 3. The lower half of the screen shows three constellation graphs that resemble bonsai trees, as well as a sun at the top left and a watering can at the top right. The circles in each constellation represent the results of respective pulse-wave measurements. The angle at which each circle is positioned represents mental health, as defined by the degree of divergence of the Lyapunov exponent, and this angle shifts clockwise when the divergence is high and counterclockwise when it is low. The size of each circle expresses the standard deviation of the divergence. With each new pulse-wave measurement, the circles migrate farther toward the perimeter, showing the data over time, while each of the three constellations shows changes in mental health status over a different section of the time series. When the pointer is moved to a constellation graph, comments appear on the CGR indicating whether there are any danger signs. Clicking on a constellation graph displays more detailed information, including a record of check-up questions. Clicking the sun elicits basic advice for boosting mental activity, while clicking the watering can elicits basic advice for calming mental activity. This enables individuals to manage their mental health easily when symptoms of concern arise, by referring to their lifestyle habits and deciding for themselves which practical steps to take for a more definite self-recovery.

3.   This completes the most basic self-check, and the CGR is normally terminated by clicking the 'x' at the top right or the 'Finish' menu option on the right.

For advanced users, we have provided convenient advanced features that allow users to edit information or to change the system parameters for different users by clicking on settings menus at the top right of each screen. In addition, using the 'Status History' menu, users can freely select up to seven data items from the record of past measurements and can create a constellation graph. This enables the users to perform self-checks and self-management from a unique perspective. The blue lines in Fig. 2 illustrate these steps.
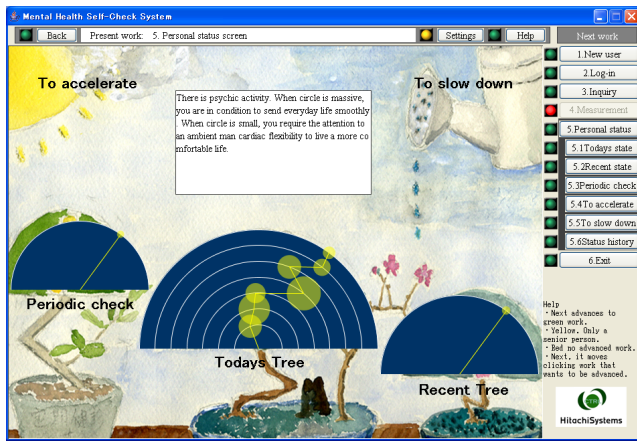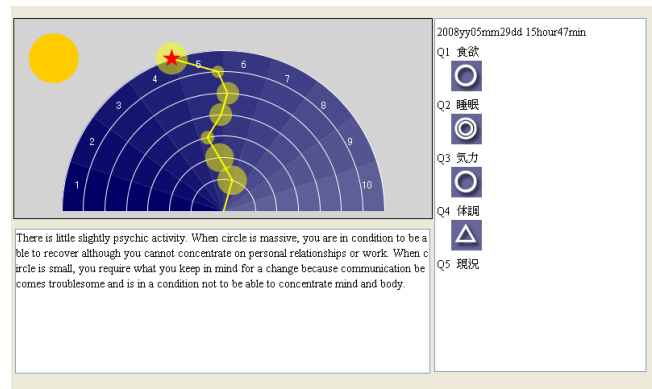
Figure 3.   Individual status screen

Figure 4.   In the example constellation graph, clockwise movement represents high divergence, counterclockwise movement represents low divergence. This graph shows seven separate measurements simultaneously. The small circle represents the standard deviation and when the cursor is placed in the center, the check-up questions display changes on the right

III.   CONCEPT

Our objectives in creating the MSAS system are explained below.

1.   Our main priority was to enable people to decide for themselves what steps to take for a more definite self-recovery when worrying mental health symptoms arise, by referring to their lifestyle habits. If it is possible to ascertain what kind of day-to-day conditions bring about high and low divergence, mental health can be maintained.

2.   Another important point is that for research purposes, the records of multiple individuals can be entered into a database and analyzed. Such analysis should enable the creation of indicators for the level of mental health in general that may require intervention, as well as the creation of more specific, practical advice to aid recovery when worrying symptoms appear.

3.   It was important that people wishing to maintain their mental health from day to day could use the system easily, without the need for an instruction manual.

4.   Since many users will be elderly, we wanted to create a system that considered the needs of the elderly as much as possible.

Regarding objective 1, our approach in developing this system is explained below, with reference to Fig. 3 and Fig. 4. These figures show three constellation graphs at the bottom of the screen, represented as bonsai trees. From left to right, these graphs are the 'Periodic Check-up Tree,' 'Today's Tree,' and 'Recent Tree,' and together they show mental health trends over time from three different perspectives: the 'Periodic Check-up Tree' shows yearly changes, 'Today's Tree' shows today's change over time, and the 'Recent Tree' shows daily changes at the same time (specifically, within 3 hours before or after a specific time) over recent days.

The method of creating the constellation graph is explained briefly below. In a pulse-wave measurement, which lasts 1 minute, the Lyapunov exponent of the time series is calculated at 43 points. With a maximum Lyapunov exponent value of 10.0 set as 180 degrees and minimum value of 0.0 set as 0 degrees, the average and standard deviation r of these 43 measurements are calculated, converted to respective angles, and displayed as vectors on the constellation graph. To display measurements from n occasions, the radius of the main semicircle is first divided into n equal parts. Then, taking the meeting points between vectors and small circles as origin points, of which there are n, each with radius r/n, these circles of radius r/n are written, and the Lyapunov exponent values are converted into angles and drawn as vectors. By connecting the vectors and small circles, the pattern shown in Fig. 4 is obtained.

For this system, we have also added a circle to the left of the constellation graphs in Fig. 4. This is called the reference circle, and is intended for comparison to the constellation graph circles, to give an idea of what a normal standard deviation should be. This reference circle is averaged from the standard deviations of many individuals, and will continue to be revised as more data are accumulated.

Returning to the beginning, in the usage scenario of the constellation graphs shown in Fig. 3, 'Today's Tree' is used to investigate the best time of day to perform a self-check. This task will tell users whether they are morning, daytime, or evening persons. Employed individuals should perform the survey separately for work days and holidays. This process will inform users of what time of day the check should be performed. Users will continue accumulating data by using the MSAS at the same time of day every day, and this gradual build-up of data will become visible in the 'Recent Tree.' When worrying symptoms appear, the MSAS issues a warning message, but this does not constitute a problem if users regain equilibrium in 2 or 3 days. Conversely, a lifestyle that habitually offers the experience of well-defined emotions will lead to large swings to the left and right, but on becoming accustomed to these swings, recovery of equilibrium will be swift. This is how strong mental health is developed. On the other hand, in a lifestyle that habitually suppresses the normal

range of emotions, recovering from a single swing to one side tends to be rather difficult. Finally, the 'Periodic Check-up Tree' is used once a year to show year-to-year variation.

Regarding objective 2, below we describe an implementation designed for multiple researchers in different locations. Data on each researcher's PC is sent to an administrator located at a research server, who then enters a copy of the data into the research database. Data in the research database can be accessed only by a specified researcher with a user ID and password.

Objective 3 is realized by enabling first-time users to follow an extremely simple set of steps, performing the most basic check simply by pressing NEXT after each screen.

To achieve objective 4, we adopted a large font in the MSAS, as recommended from the perspective of accessibility.

IV. DISCUSSION

Using MSAS, individuals can perform self-checks for mental health and can also self-manage. If it is possible to ascertain what kind of day-to-day conditions bring about high and low divergence, mental health can be maintained. We are also confident that if self-management no longer becomes possible, and the individual consults a counselor or psychiatrist, this system can aid in the early detection of depression or dementia, or prevent further deterioration of mental health. Furthermore, we think the ability to send and receive data related to mental health indicators across networks constitutes an unprecedented innovation in communication. However, it is essential to take great care in data management in light of the issue of confidentiality, which has become important in recent years. To deal with this issue, the trial version incorporates two layers of user ID and password control: one at MSAS log-in and one at database log-in. In the commercial version, we plan to further enhance protection by using data encryption.

In developing the MSAS for practical use, we hope to make the following improvements, taking advantage of the anticipated accumulation of large amounts of information.

A. Establishing a more objective evaluation framework

When data have been obtained from a large population, divergences in mental health (radial angle on the constellation graph) and the amplitude of the standard deviation (reference circle) can be averaged to obtain the normal divergence and normal variation (standard deviation). In addition, with sufficient data, normal values can be obtained for specific populations, such as those differentiated by age and sex. By comparing these normal values to the divergence and standard deviation of the MSAS user, it should be possible to indicate the presence of worrying symptoms with greater objectivity on the MSAS.

B. Creation of more practical advice

When worrying symptoms are detected, self-management will become easier for users if the MSAS can create practical advice on the best measures to take. With each pulse-wave measurement, responses to check-up questions are paired with the users' individual attributes, and the condition of the users at the time of measurement is included with these answers. Therefore, by analyzing large amounts of accumulated data, correspondences can be made between pulse-wave measurement data and the users' condition across various contexts. Using this information, it should be possible for the MSAS to offer more practical advice to suit each individual. In addition, we are confident that the accumulation of large amounts of information will be useful in the future in various kinds of pulse-wave research.

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