Real Time Spatiotemporal Biological Stress Level Checking

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Abstract: We are going to investigate and design a healthcare navigation system that consists of sensor devices for human's vital sign, a mobile terminal for transferring the vital data to the cloud, and a cloud computing environment for intelligential processing of the vital data. In this paper, we present a tool for the mobile terminal, i.e. a smartphone, which displays user's biological stress levels. Although the tool is a part of our healthcare navigation system, it does not require the computation resource of the cloud because the stress levels, LF/HF, are enough computable on the processor of the current smartphone in real time. LF/HF is an index of sympathetic nervous activity calculated with the heart rate data obtained from heartbeat sensors. The LF/HF values are displayed in a form of bar graph at user's current location on the Google map of the smartphone. The location information is easily obtained from the GPS of the smartphone. Using the tool, the user can see his/her current stress levels as bar graph on the Google map in real-time. Namely, the tool provides users with their spatiotemporal biological stress levels in real time.

1. Introduction

Over the past 20 years, the CPU performance, the HDD capacity, and the internet bandwidth have improved 1,000 times, 20,000 times, and 15,000 time, respectively. As a result, cloud computing is available among the world. With the rapid expansion of the computation resource, the idea of life computing is aborning. Unlike existing scientific computing, life computing supports our human life. The demand is exceeding the demand of scientific and engineering calculations. We are just going to investigate and design a healthcare navigation system. We believe that this healthcare system will be a major field of life computing. Healthcare computing consists of sensor devices for human's vital sign, a mobile terminal for transferring the vital data to the cloud, and a cloud computing environment for intelligential processing of the vital data. Then this system sends appropriate and useful recommendation about healthcare to the user. In this healthcare navigation system, a mobile terminal gets the vital data from sensor devices to transfer them with applying appropriate pre-processes to the cloud. It is sometimes possible to directly provide the user with information about his/her health condition at the mobile terminal without using computation resource of the cloud. In this paper, we develop a tool for a mobile terminal, i.e. a smartphone, which displays LF/HF that is a method to measure

stress levels in real time as a part of our healthcare navigation system. The LF/HF values are displayed in a form of bar graph at user's current location on the Google map of the smartphone. Frequency analysis is applied to time series data for heart rate variability. Its power spectral includes LF that is low frequency and HF that is high frequency. The ratio of LF to HF is used for an index of stress levels (sympathetic nervous activity). Extreme stress causes various physical harms. It is helpful for us to reduce stress for spending healthy life. The tool does not require any computation resource of the cloud because LF/HF are enough computable on the current smartphone in real time. The location information is easily obtained from the GPS of the smartphone.

Instant Heart Rate produced by Azumio[1] and Period tracker[2] produced by GP Apps are examples of existing healthcare services. The former can measure heart rate by using camera equipped with most smartphones. The application measures pulse waves by pressing the camera with a finger. When user inputs the start date of menstruation, the latter can predict the next menstruation and next ovulation date. In these services, user consciously provides his/her vital data for these services. These services influence user's daily life owing to the device size. A healthcare system needs to measure at all times for predicting user's condition accurately. However, the size of the heart rate sensor which is used in this paper is 40.8*37.0*8.9 cubic millimeter and weight is only 13 grams including a battery cell. This sensor can be put on user's body directly at all times. User only has to put on the heart rate sensor to send vital data. This sensor does not influence user's daily life. The tool which we present here notifies user of his/her stress levels without sending user's vital data to the cloud.

In the case that just time and LF/HF are displayed, it is difficult to predict what situations cause stress. Not only time and LF/HF

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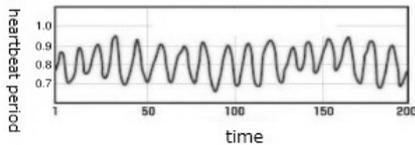g)   joe@ics.nara-wu.ac.jp

Fig. 1　Heart rate data

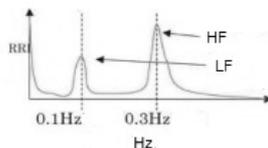**Fig. 2**　Time series data of heart rate variability

Fig. 3　Frequency analysis

but also other information is required to solve this problem. One of the factors that give stress is location information. Getting stressed or relaxed may depends on the surrounding. The action at the notable time can be predicted from the location information. In this tool, the association of the location information and LF/HF can be predicted in what situations cause stress. It helps to reduce stress for spending healthy life.

The rest of the paper organized as follows. In section 2, LF/HF which is an index of sympathetic nervous activity is described. In section 3, we explain the requirement specification and the implementation of the tool. In section 4, we show some examples of the execution of the tool.

2. Heart rate data

This section explains the heart rate sensor used to take the heart beat and the calculation method for LF/HF as the index of the stress used in this paper.

2.1 Calculation of LF/HF

As shown in **Fig. 1**, various shapes of waves such as P, Q, R, S, and T waves are included in each heart rate. The RR interval is an interval of R waves that is the biggest peak wave in each heart rate. It is known that the RR interval is synonymous with the heart rate, and always changes constantly.

As for the evaluation of the autonomic nervous function, the index of the frequency domain obtained by the spectral analysis is used [3][4][5]. **Fig. 2** shows time series data of heart rate variability. The horizontal axis and the vertical axis are time and RR interval, respectively. **Fig. 3** shows frequency analysis of time series data of heart rate variability. Its power spectral includes LF which is low frequency and HF which is high frequency. LF is related to the change of blood pressure and influenced by both

Fig. 4　heartbeat sensor

parasympathetic and sympathetic nervous system. HF is related to breathing variation and influenced by parasympathetic nervous system. The sympathetic nervous system promotes the shrinking of the blood vessel, the increase of the heart rate, and the reaction of the muscular tension etc., so that it reacts to the change in the situation quickly, and the stress like uneasiness, fear, and anger, etc. has been received. Parasympathetic nervous system promotes responses which include the decrease of the heart rate, decreased blood pressure, and muscle relaxation, etc. Sleeping and getting relaxed, parasympathetic nervous system works.

The index of the sympathetic nervous system is calculated with the ratio of LF to HF. HF decreases while LF appears when a stress is received. When parasympathetic nervous system becomes active, HF increase. Therefore, getting stress and relaxed make LF/HF large and small, respectively.

LF/HF is calculated with time series data of heart rate variability. The time series data of heart rate variability is applied to linear interpolation or spline interpolation to get equal interval samples. Power spectrum of sampling data is calculated using Fourier transform or an autoregressive model. LF and HF are set to area of 0.05Hz - 0.15Hz and 0.15Hz - 0.40Hz, respectively.

2.2 Heart rate sensor

Fig. 4 shows WHS-1 manufactured by union tool corporation [6] that is the heart rate sensor we use. This sensor detects and calculates the RR interval. It is possible to use it without interfering in user's daily life by putting directly on the skin with an electrode pad because the size is so small (40.8*37.0*8.9mm), and the weight is very light (only 13 grams) including a battery cell. WHS-1 also includes an acceleration sensor and a temperature sensor as well as the heart rate sensor so that it detects the change of user's body movement and measures his/her body surface temperature.

WHS-1 supports two types of data transmissions. One method is sending data to a PC using wireless communication. The other method is sending data to a PC using a flash memory. In the case of wireless communication, it can also output the heart rate waveform instead of the RR interval.

In the case of outputting RR interval, heart rate signal, which are measured by an electrode attached to the sensor, is sampled at 1,000Hz. Then RR interval is calculated by predicting the interval between R waves which are found in the heart rate waveform. A flash memory with16MB saves almost one week RR intervals data.

3. Displaying LF/HF in real time

In our future healthcare navigation system, vital data is transferred to the cloud via a smartphone. A smartphone can effectively utilize the information from the sensor device. In this paper, LF/HF is calculated with the vital data, and GPS equipped with the smartphone is used. We develop a tool that displays LF/HF values on the map at the user's location in real time. In this section, we explain the requirement specification and the implementation issues of the tool.

3.1 Requirement specification

The stress might be received in unconsciousness to cause deconditioning as a result while we learn the condition of our daily life by knowing the changing of LF/HF values. However, this is just an understanding when to have caused the stress and the relaxation. Since it is difficult to know which situation has caused the stress, not only time but also other information are necessary. By using time and other information, we can predict the factors which bring down the stress. As such extra information, location information is easily given with GPS, for example. The LF/HF value and the location information help us predict our condition at that time. Then the relation between our stress and our daily life is clarified. In the proposed tool, the LF/HF value should be displayed on the map at user's current location.

Fig. 5 shows the correlation of each function. LF/HF value is calculated and displayed by numerical characters every 10 seconds. Moreover, the value is shown with a bar graph at user's present location on the Google map of a smartphone every 60 seconds. When user swipes on the screen, the map works with the swipe. When user touches on the screen, a zoom item is displayed and the map can be zoomed in or out. When the menu button is pushed, the MyLocation item, the Reset item, and the On/Off item are displayed. When the MyLocation item is selected, the present location is displayed at the center of the screen. When the Reset item is selected, the LF/HF bar graph displayed on the screen is deleted. When the On/Off item is selected, the bar graph is displayed or hidden on the screen. The specification to achieve the above-mentioned functions is as follows.

(1) The LF/HF value is displayed in digits every 10 seconds.
(2) The LF/HF bar graph is put at the present location on the Google map every 60 seconds.
(3) User's movement information on speed, distance, altitude, and traveling direction, etc. are displayed.
(4) Swipe of the map
(5) Zoom of the map
(6) In the case of the expanded map, it switches from the bar graph to the label.
(7) The present location is obtained.
(8) The LF/HF value is display or hidden.
(9) The displayed LF/HF value can be deleted.
(10)The mobile terminal and the sensor are communicated with Bluetooth.

In function 1), the LF/HF value that presents stress level is displayed and updated every 10 seconds so that user can confirm the LF/HF every 10 seconds.

In function 2), user can confirm the change of his/her stress level by looking at the displayed LF/HF bar graph every 60 seconds. The more heart rate data, the more accurate LF/HF is calculated. When the LF/HF value is displayed as numerical characters, it is difficult to confirm the change of the LF/HF value viscerally. To solve this problem, a form of bar graph is adopted. A series of bars along user's move makes the user confirm the change of the LF/HF value viscerally. User can understand what situation causes a stress by confirming the change of the LF/HF value which is drawn at user's current location on the Google map at that time.

It is known that exercise influences LF/HF. So the relation between exercise and LF/HF is effectively predictable by giving the information of user's exercise. In function 3), exercise information such as speed, distance, elevation and direction are displayed.

In function 4), when user swipes the screen, the Google map moves accordingly. The user can see the LF/HF value of any location by using swipe.

In function 5), the Google map can be zoomed in or out. When the wide range is displayed, the change of the LF/HF value can be roughly confirmed. On the other hand, when a small range is displayed, the relation between the place and the LF/HF value can be observed in detail. When two or more bar charts are displayed by the large scale, the LF/HF value is not confirmed easily. Then, in function 6), it switches to the label from the bar chart to the integer portion of the LF/HF value.

In function 7), user's current location is put at the center of the screen using the GPS of the smartphone so that he/she confirms his/her location any time.

In function 8), user can display or delete the LF/HF bar graph/numeric characters. When he/she wants to see just the Google map, the display of the LF/HF value may make the screen hard to see.

Function 9) is used for deleting the record of the LF/HF value data. When a lot of the LF/HF value data is recorded, various functions might not be able to be operated smoothly. Function 9) is used to prevent such cases.

The tool we present in this paper is executed on a mobile terminal emulator on a PC, and does not use the Bluetooth communication. Since this is a hardware restriction, we will easily support the Bluetooth communication very soon using a real mobile terminal.

3.2 Implementation

When our tool is invoked, user's current location is displayed by using GPS on the Google map. Then, it starts reading the heart rate data from WHS-1. The LF/HF value is displayed and updated by digit in the upper part of the screen every 10 seconds. In addition, the current location is displayed at the center of the screen, and user's moving information of speed, distance, altitude, and direction are displayed, too. The LF/HF bar graph is put on the Google map to be updated with an interval of 60 seconds. The acquisition of the current location, the calculation of LF/HF, and the explanation of GUI are presented as follows.
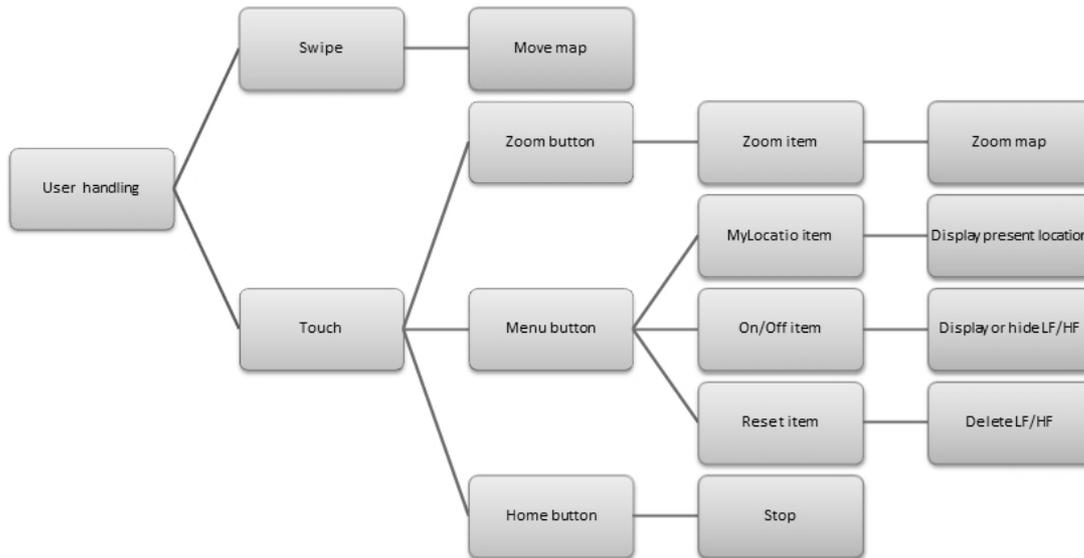
Fig. 5 correlation of each functions

3.2.1 Acquisition of user's current location

The GPS of the smartphone is used to acquire user's (namely smartpone's) current location. The application makes use of Google Map API [7]. Google Map API provides Maps API and Maps Javascript API that are widely used for smartphones. In this paper, we adopt Maps API because Maps API Key is necessary to control the Google Map. When the location information is required, an API called Location-based Service that enhances GPS functions is used in smartphones. The GPS acquires the location information by way of LocationManager. The getSystemService method obtains LocationManager, and begins to acquire the location information of latitude, longitude, altitude, direction, and speed, etc. The update notification for the location information is set by the requestLocationUpdate method, and sent to the LocationListener interface. Function 7) is implemented with these APIs.

For the requirement specification regarding to the location information (Function 3)), an object of the Ctiteria class is sent to the Provider as a parameter. The distanceBetween method calculates the distance from the starting point to the current point.

3.2.2 LF/HF calculation implementation

In this subsection, we explain the implementation issues for calculating LF/HF. X and Y are provided for time and the RR interval, respectively. Then, a spline interpolation is applied to the sampling data with an equal interval. The power spectrum is calculated from the sampling data with the equal interval by a Fourier transform. The areas of LF and HF are 0.05Hz - 0.15Hz and 0.15Hz - 0.40Hz, respectively.

Heart rate data is sent from WHS-1 every 3 heart beats. Then the received data is stored in a circular buffer, which is implemented with an array and modulo operations for the array index. Using the circular buffer, the data which become unnecessary is overwritten with new data to avoid consumption of memory. As is easily expected, the more heart rate data, the more accurate LF/HF is calculated. We investigate the tradeoff between the circular buffer size and the LF/HF accuracy to decide the buffer size

for 60 seconds data. The initial LF/HF is calculated with the data of first 60 seconds. After the first calculation, LF/HF is calculated every 10 seconds using the last 60 seconds data, which occupies the circular buffer. Each new 10 seconds data is overwritten to the oldest 10 seconds data.

In this way, LF/HF is obtained every 10 seconds, so function 1 is satisfied. In addition, LF/HF is also obtained every 60 seconds, so Function 2) is satisfied.

3.2.3 GUI

In the screen of the smartphone, the information of LF/HF, speed, distance, elevation and direction is displayed on the upper part. Since the information is updated every 10 seconds, Function 3) is satisfied. The Google map is displayed below the information area. The MyOverlay class is used to draw a bar graph of LF/HF at the current location on the Google map, and Function 2) is satisfied.

The Google map moves at the same time as user swipes. When user swipes, the touching point moves with user's finger. User can move the Google map to confirm the LF/HF value anywhere. Namely, Function 4) is achieved.

The SetBuiltInZoomControls method is used for the expansion and reduction of the Google map to satisfy Functions 5) and 6). The LF/HF value is expressed as digit label or bar graph depending on the scale of the Google map. The digit label is the current LF/HF value while the length of the bar graph is the LF/HF value at that point. In the case LF/HF is expressed as bar graph on the small scale of the Google map, the LF/HF value is not confirmed easily. Moreover, in the digit label on the large scale map, the change of the LF/HF values is not confirmed easily. The onZoomListener method is needed to solve this problem.

The onCreateOptionsMenue method is used for setting menu buttons equipped with smartphones. When the menu button is pushed, menu items which include MyLocation, Reset and On/Off are displayed. When user select an item, the Item.getItemId method judges which item is selected. The selected item is processed by the onOptionsItemSelected method.
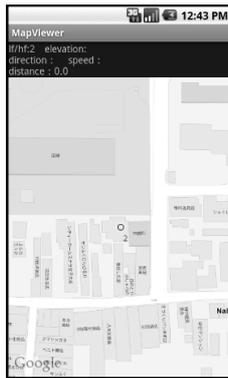
Fig. 6　The screen of the tool at 60 seconds after the invocation

(a)initial state　　　　　　(b)result

Fig. 7　swipe

(a)initial state　　　　　　(b)result
Fig. 8　zoom button

(a)initial state　　　　　　(b)result

Fig. 9　MyLocation item

When the Mylocation item is selected, the current location is obtained to be displayed in the center of the screen. When the Reset item is selected, the record of the LF/HF values is deleted. When the On/Off item is selected, the LF/HF value is displayed or hidden. In this way, Functions 7)-9) are satisfied.

4. Example of behavior

In this section, we explain the performance of our tool that is an Android application. The tool is developed with Java SE Development Kit, Android SDK, and Eclipse. Java SE Development Kit is used for developing Java applications. Android SDK is for the development of Android applications by Java. Eclipce is an integrated development environment. The heart rate data is obtained from WHS-1.

In this paper, we use heart rate data which is preliminarily obtained from heart rate sensor and display the LF/HF bar graph at arbitrary location. We believe it is enough to investigate whether Function 1)-9) are achieved.

Invoking the tool, the screen after 60 seconds is shown in **Fig. 6**. Each LF/HF is calculated and updated every 60 seconds. Since the LF/HF bar graph is put at current location, user can predict the correlation between stress and location information. The LF/HF value shown in Fig. 6 is calculated with the data of the initial 0-60 seconds. In the upper part of the screen, LF/HF, altitude, speed, direction, and moving distance are displayed and updated every 10 seconds.

Fig. 7 shows the change of the screen by swipe. Fig. 7(a) is the initial state. When the screen is swiped from right to left, the screen moves left according to the swipe. Fig. 7(b) shows the re-

sult of the swipe. Using swipe, user can confirm his/her LF/HF vale at any location.

In **Fig. 8**, when user touches the screen, the zoom item is displayed. Fig. 8(a) is the initial state. When the plus icon in the zoom item is selected, the Google map is zoomed in. Fig. 8(b) is the zoomed screen by the plus icon. On the other hand, when the minus icon in the zoom item is selected, the Google map is zoomed out. The LF/HF values are shown as bar graphs on Fig. 8(a) while the LF/HF values are shown as the digit label as on Fig. 8(b). The toggle for the bar graph and the digit label is the zoom scale of the Google map. The LF/HF bar graph changes to the LF/HF digit label when the zoom scale exceeds the predefined value. The length of the bar graph presents the LF/HF value at that point. On the small Google map, two or more bar graphs represent the change of the LF/HF values viscerally. User can understand where his/her stress arises. On the other hand, the digit label presents the integer part of the LF/HF value at that time. On the large Google map, user's past and present locations are displayed in detail. The user understands the relation between the LF/HF value and his/her moving path. Therefore, the switch of the bar graph and the digit label is useful to understand what situation causes his/her stress.

Fig. 9 shows the screen applied by the MyLocation item. When the menu button of the smartphone is pushed, the menu item is displayed at the bottom of the screen as shown in Fig. 9(a). In the menu item, the MyLocation item, the On/Off item, and the Reset item are included. When the MyLocation item is selected, the current location is acquired to be displayed at the center of the
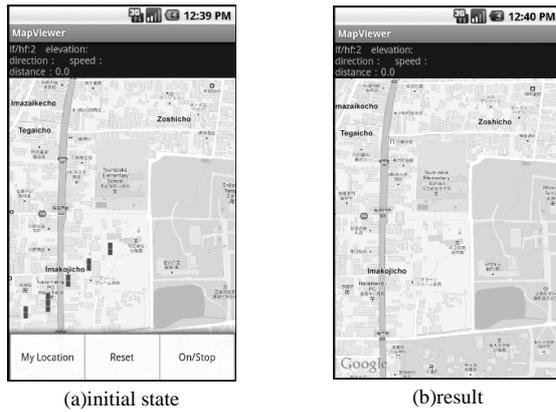
(a)initial state　　　　　　(b)result

Fig. 10　On/Off button
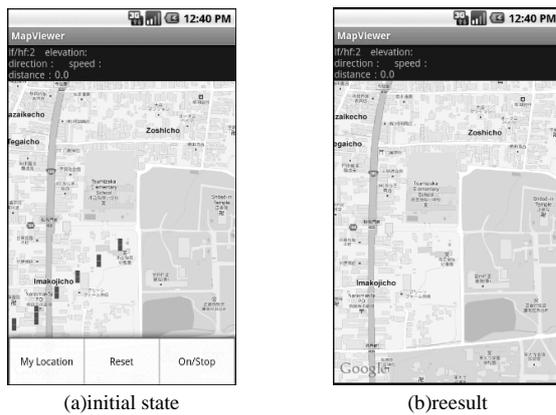

(a)initial state　　　　　　(b)reesult

Fig. 11　Reset button

screen. In Fig. 9(a), the current location is not displayed. When the MyLocation item is chosen, the current location is displayed at the center of the screen as shown in Fig. 9(b). User can confirm his/her current location at any time.

Fig. 10 shows the screens where the On/Off item is used. When the On/Off item in the menu item is selected, the LF/HF bar graphs are displayed or hidden. Fig. 10(a) shows the screen with the LF/HF bar graphs. Using the On/Off item, the LF/HF bar graphs are hidden as shown in Fig. 10(b), and user can take a detail look at the Google map without the LF/HF bar graphs. When the LF/HF bar graphs are hidden, the LF/HF value is calculated every 10 seconds. Using the On/Off item, the LF/HF bar graphs appear again.

Fig. 11 shows the screens where the Reset item used. When the Reset item is selected, the LF/HF bar graphs as shown in Fig. 11(a) are deleted. Then, the LF/HF bar graphs begin to be displayed. When a lot of LF/HF bar graphs are displayed, various functions might not be able to be operated smoothly. This item is used to avoid this problem.

5. Conclusions

In our ongoing healthcare navigation system, vital data from sensor devices are sent to a portable terminal such as smartphone to process the data including error correction. The processed vital data are sent to a cloud for intelligent processes. In this paper, we showed that it is possible to show some of user's conditions to the user without cloud resource, but with just a smartphone.

In this paper, we presented a tool for a mobile terminal that

displays the LF/HF value in real time as an index of user's stress level. The LF/HF value is calculated by using heart rate data obtained from a heart rate sensor WHS-1, and displayed at user's current location in the Google map. Some physical conditions cause various slumps by an excessive stress. User can understand what situation causes his/her stress by using the location information and the LF/HF values. When the source of stress is detectable, user can easily improve his/her daily life. It leads to the environment improvement to find the reason of stress brought on by location such as noise.

In this tool, the LF/HF value is immediately calculated every 10 seconds. To confirm the change, the LF/HF bar graph is drawn on the Google map. The information of speed, distance, elevation and direction is displayed to predict the relation between the exercise and the LF/HF value effectively. The Google map can be zoomed in/out, and swiped freely. The LF/HF value is shown in a form of bar graph to understand the relation between user's location and LF/HF value in the small scale Google map, and the LF/HF value is shown in the digit label in the large scale. The user can confirm his/her current location at any time. When user wants to look at the Google map, the LF/HF value can be hidden. To operate various functions smoothly, the LF/HF value record can be deleted. In this paper, we develop a prototype to show the actual execution.

For our future work, it is necessary to include other information such as user's acceleration and some environment information such as weather. The information helps user predict his/her situation more precisely. Another method to calculate the stress level with electro-oculogram is needed to improve the accuracy of the stress level.

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