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Active Self-Tracking and Visualization of Subjective Experience using VAS and Time Spirals on a Smartwatch

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Abstract
In this paper, we describe a smartwatch-based system that enables self-tracking and registration of subjective experience (such as pain) using a VAS-like scale, as well as allowing the acquired data to be visualized directly on the smartwatch. The data visualization is tailor-made for the round smartwatch form factor using an interactive time spiral. Our proof-of-concept prototype implementation is described along with a case study where the application has been used to self-track back pain as the phenomenon of interest. It is found that the smartwatch allows momentary self-registration when the phenomenon occurs and that the spiral structure of the data visualization facilitate identifying recurring patterns in the data.

Author Keywords
Active self-tracking; Self-reporting, Self-reflection; Smartwatch; Time spiral; Visual Analogue Scale.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Self-tracking has received a lot of attention the past decade in part due to the technological developments of low-cost computing and sensing devices, including activity track-

Figure 1: A Visual Analogue Scale (VAS) mapped onto the edge of an analogue clock face. This way the scale has a length of 9.8cm close to the standard 10cm VAS

Figure 2: Data visualization using a time spiral on a 12 hour analogue clock face. Each hour is color-coded green-red to indicate number of data points or severity of the observations (e.g. of a symptom)

ers, step counters, heart rate and sleep monitoring devices. Meanwhile, the Quantified Self-community has provided a forum for people engaging in the self-tracking and self-experimentation culture to share experiences and knowledge. In the commercial space, the main focus has been on passive sensing of mainly physical activity, heart rate and sleep monitoring leaving less attention to active tracking of subjectively experienced phenomena. In the Quantified Self community many experiments and self-tracking projects have involved tracking of subjective phenomena including mood, pain, symptoms and other subjectively experienced phenomena. However, off-the-shelf tools supporting tracking of subjective experience has not been readily available.

We note that there are certain phenomena that cannot be passively measured, such as, pain, mood, anger or even basic events such as sneezes or allergy symptoms. Having easy to use data acquisition instruments for active self-tracking allow quantification of such phenomena.

In this paper we explore smartwatches as a platform for active self-tracking, data acquisition and data visualization. Our goal is to create a self-tracking data acquisition smartwatch app for self-registration of observations of subjectively perceived phenomena. Furthermore, the aim is to annotate each observation data point with relevant meta-data including time, location, and physical activity sensing data in order to allow analysis of the observed phenomena in relation to those contextual data. For instance to understand the spatio-temporal patterns of the phenomena, e.g. if a symptom occurs at certain hours of the day, days of the week, or at certain locations. To illustrate the system we describe a case where it has been used to self-register occurrences of back pain. Through registration of the perceived level of pain using the VAS and exploration of the collected data directly on the smartwatch clock face.

A Smartwatch Personal Informatics System

Our proposed smartwatch-based personal informatics system [12] includes an input component for data collection and a data visualization component for reflection.

First, for input, the approach adapts the Visual Analogue Scale (VAS) to a smartwatch clock face. By bending the scale and positioning it at the edge of the smartwatch display we obtain a length very close to the standard 10cm VAS [15] [13], see Fig. 1. By sliding the finger at the edge of the touch display an indicator (the black marker) can be positioned on the scale. When the user has positioned the marker the observation is confirmed by pressing a button in the center of the display. The smartwatch provides visual as well as haptic feedback to indicate to the user that the data has been registered.

Second, the system allows direct visualization of the collected data on the smartwatch clock face. Again, we aim to utilize the round analogue watch form factor and therefore choose to show the continuous time series in a time spiral. This allows us to utilize the round property of the display by mapping a relatively large amount of data onto a relatively small space, see Fig. 2. Touch-based gestures allow the user to navigate the visualization. An advantage of this type of visualization is that it allows the user to easily observe recurring temporal patterns, which might be harder to distinguish in conventional plots (e.g. line plots or bars plots).

Related Work

In the last decades, experience sampling (ESM) and ecological momentary assessment (EMA) [16, 1] have been supported with different types of computer-based solutions. Studies have shown higher compliance rate and better quality data using electronic self-registration solutions compared to paper-based diaries [7].

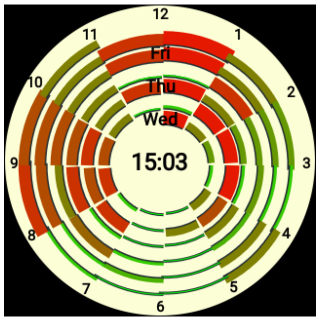

Figure 3: Visualization 1a – Pain level represented as a combination of the color code (red, orange, green) and the height of the arc mapped to an observation in granularity of hours

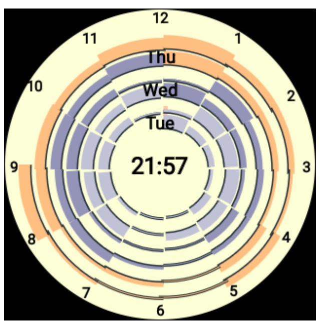

Figure 4: Visualization 1b – Separates the different days using different colors. Thereby making it easier for the user to see which day the hour slots belong to. Pain level by hour is indicated by the height of the arc

Most recently smartwatches have been introduced as a platform for ESM and EMA solutions [4, 5]. Recent studies have shown promising results of using smartwatches for ecological momentary assessment [8]. In part due to the convenience of the devices being easily accessible and that the registrations can be done with very brief interactions. Further simplification of the data acquisition step using *smartbuttons* have demonstrated the ability to collect self-reported data (symptoms) at a high frequency that is unthinkable using traditional methods [11].

Using time spirals to visualize time series is a known approach applied to different data types [18, 6]. A time spiral visualization related to a clock face was explored in SpiraClock [3], which provides a calendar directly on an analogue clock face. However, that was explored as an early web-based approach. In earlier work we have also explored the concept of using time spirals for visualizing personal data, which have the inherent properties of recurrent patterns [10]. At that point, the approach was deployed as a visualization method for smartphones, as opposed to the smartwatch deployment described in this paper. Unlike previous solutions, a smartwatch facilitates direct availability of the collected personal data, similar to the activity visualization complication found on the watch face on the Apple Watch.

VAS Input on a Smartwatch

A user-driven personal informatics system requires attention to the interface for data collection [12]. In the following, we assume that the system is used for pain assessment and the VAS is used for registering the subjectively experienced pain level [14]. The Visual Analogue Scale is presented on the smartwatch watch face as shown in Fig. 1, and the pain level scale is mapped to color codes: strong green represents no pain, while strong red is mapped to the strongest pain. The gradient represents all the intermediate values between no pain and severe pain. This way we deploy an analogue scale that avoids the potential bias discrete indications would introduce [9].

Unlike previous VAS implementations on smartwatches, we have chosen a design where the length of the VAS is 9.8 centimeters. That is the measurement in our present prototype implementation, which is using an Android-based [2] LG Watch Urbane with a 1.3 inch round display corresponding to a circumference of 10.4 centimeters. Deploying our prototype on smartwatches with different display sizes would obviously lead to different measures. The round design alongside the edge of the screen has been chosen in order to maximize the length of the scale and allowing users to more accurately input data (the fingertip of a person is usually about 10mm wide or 48 CSS pixels [17]). The user may use his/her finger to swipe on the VAS for choosing the pain value and then press an OK button in the center of the display in order to confirm the observation. The timestamp and the pain assessment value will automatically be saved for the user. A *swipe right* gesture enables the user to cancel the VAS input without making an observation. Two or more consecutive observations within one minute will be discarded and only the last one kept. This allows the user to correct if the confirm OK button in the center of the display was pressed by mistake while adjusting the marker on the scale.

Time Spiral Visualization on a Smartwatch

The collected observations are stored chronologically and drawn on the spiral starting from the center of the screen and continuing clock-wise. The spiral is set to display the events on an analog scale using 12 hours similar to a standard clock face. By default, the past three days are shown. Events are represented between two adjacent hours on

Figure 5: Visualization 1c – Is a simple variant where only one color is used. The pain level is mapped to the height of the arc corresponding to the time of the observation by hour

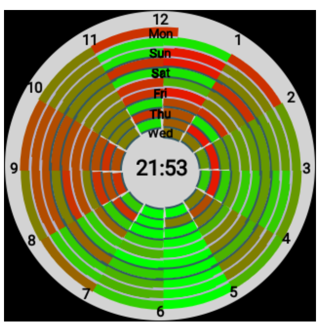

Figure 6: Visualization 2 – The color code of the observation is displayed in the spiral timeline with no emphasize on the adjacent days of the week

the watch. The color of the arc represents the pain level recorded at a specific point in time. Specifically, colors such as green represent low or non existing pain values, while orange and red represents intermediate to high values of pain, see Fig. 3 as an example. The user is able to interact with the spiral visualization using touch-based gestures, which include:

- swipe up for fetching observations from the past;
- swipe down for navigating through events until the current time;
- swipe left to open a new Visual Analogue Scale input to add a new observation.

At this stage, the user is able to explore and identify patterns (e.g. time intervals with low/high pain levels) and then take informed actions based on the reflection. An example could be a person suffering from a chronic disease who wants to explore the temporal relation between subjectively perceived pain and time (hour of the day) taking medication.

Prototyping Visualization Configurations

Due to the relatively small display on a smartwatch (in our case 1.3 inches) providing a readable visualization on the limited display area is not trivial. At present we have explored different visual configurations of the data visualization. In the following, we describe our designs and experiences.

Spiral Visualization 1

The first visualization configuration aims to display the pain level as the height of the arc between two adjacent hours, when an observation was made during the particular hour. The maximum height of an arc is 20 pixels, corresponding to the most severe pain level. In the center of the visualization, the current time is displayed, and following the spiral towards the outer rings, every two adjacent rings compose a day (2×12 hours). The alternating days are marked with the corresponding names at the time they begin. The visualization is shown in three different variants: The first (Fig. 3) also use color gradients to indicate the severity of the pain in different hour slots. The second variant (Fig. 4) separates the different days with different colors. Since one day consists of two rings the colors emphasize which day the rings and different hour slots belong to and makes it easier to distinguish the end and the start of the following day. The third variant (Fig. 5) uses just one color and the pain level is indicated by the height of the arc.

Spiral Visualization 2

The visualization shown in Fig. 6 allow more days to be represented on the time spiral, considering the display resolution of the LG Watch Urbane used for prototyping (320×320 pixels, 1:1 ratio, ~245 PPI density). In the example in Fig. 6 five days are displayed, which provide more available information to the user than the three days used in the previous figures. This visualization has been found to be more adequate for observing repetitive patterns, simply because of the increased quantity of represented data and the colored arcs mapped to the events (e.g. the time interval from 02:00–07:00 compared to the interval 08:00–10:00). An advantage of this configuration is the consistency having the VAS input pain level colors correlate to the colors shown in the time spiral visualization. Underneath the arc representing an observation, there is a thin arc with a specific color for the day of the week. The starting of a new day on the spiral is marked with a three-letter abbreviation (e.g. Mon, Tue, etc.), and the next 24 arcs representing a day have the thin arc/line underneath using the same color. The color of this underline alternates every 24 arcs, assisting the user to

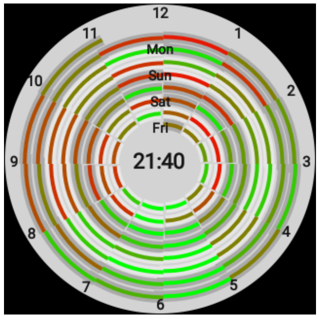

Figure 7: Visualization 3 - Emphasize the different days of the week by alternating the background colors of the spiral using different gray scale for adjacent days

distinguish days in the time spiral.

Spiral Visualization 3

The visualization shown in Fig. 7 uses a different approach to assist the user in differentiating between days. Every two consecutive days are represented with a grey and white background colors alternating. In this configuration color gradients are used to show the registered pain level. However, in our experience, this configuration is less efficient in terms of recognizing patterns because of the reduced width of the spiral, compared to Spiral Visualization 2.

Case: Self-Tracking Back Pain

As a proof-of-concept, an N=1 self-tracking experiment was set up using the smartwatch based personal informatics system. The phenomenon of interest was back pain as experienced throughout the day and the purpose was to see if relations to other phenomena could be observed. The self-tracking experiment was carried out for a duration of four weeks and had only one subject actively tracking back pain. The subject was able to use the smartwatch VAS input in order to actively collect data points mapped to the pain severity of the backbone (i.e. green color code for low or non-existing pain and red for a high pain level). Depending on the subjective assertion of pain present at any time of the day, 54 observations were made during the four weeks experiment. The interactive time spiral visualization 2 (Fig. 6) was used to reflect and visualize the collected data. Through self-reflection, the test subject noticed by interacting with the spiral visualization, that the back pain was most severe during evenings (high density of red/severe observations within the 7:00 - 10:00 PM interval, compared to the reduced observations number between 12:00 - 7:00 PM). Moreover, it was found that back pain was experienced especially after days with workout sessions. Again, through self-reflection, the test subject was aware of his workout programme and using the spiral visualization was able to identify a higher number of severe observations in the days with the workout session compared to the days with no physical activity. Additionally, the self-tracking data suggested that weather might be an influencing factor as well. That is, the colder and windier it was during a day, the more severe back pain was found in the data. The test user browsed through the weather reports history during the experiment period and by gesture interactions with the spiral visualization was able to fetch data from the beginning of the experiment. A possible correlation was observed, as a slightly higher number of red/painful observations were made during cold and windy days. However, due to the short time span it was unclear if the relations found were coincidental.

Discussion and Conclusion

The back pain case has illustrated the use of the VAS for data collection and the time spiral data visualization to support self-reflection. The subject found it easy to observe the repetitive patterns and distinguish them on the time spiral visualization. Through self-reflection based on the collected data, the subject obtained new ideas for self-experimentation projects that would involve adding one more gap day between workout sessions in order to see if that would lower the back pain. Another self-experiment involved not to bike during windy cold evenings. Even though the experiment cannot be considered conclusive due to the limited duration, it serves to illustrate the point of having a simple personal informatics system at hand, that allows the user to collect data on subjective experiences and reflect on the data. It serves to illustrate the main goal of providing the user with means for tracking symptoms and use that to take informed actions based on data (e.g. the gap day between workouts in the case).

We have demonstrated a smartwatch-based personal informatics system that allows both the collection of subjective experience assessed on a VAS and a visualization of the collected data using time spirals. Different configurations of the data visualization have been discussed. As a proof-of-concept case, the smartwatch system was applied in a four week self-tracking experiment where the participant collected data with self-assessed back pain. Exploration of the collected data on the smartwatch led to a couple of new insights and provided ground for further self-tracking experiments.

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