Multi-Device Visualisation Design for Climbing Self-Assessment

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***Abstract*—While quantified-self applications and wearable sensors for running, cycling or strength training are receiving broad interest from science and industry, little attention has been paid to the increasingly popular climbing sport, so far. To fill this gap, specialized wrist-worn sensor devices for tracking climbers have been developed recently. To support climbers and make the best of the available sensor data use possible, we designed a set of interactive visual interfaces which provide detailed insights into training data and support self-assessments of various aspects of the climbing technique. Our approach consists of a mobile web application to be used during the training and a desktop tool for presentation and analysis. In our design study we conducted semi-structured interviews with climbers, developed a scenario-based prototype in D3.js and evaluated our prototype. The initial interviews, a formative expert review and a summative usability study indicate the importance of providing manual input possibilities in addition to the automatically detected data and visualization techniques showing an overview of their training data. The findings of this design study provide an understanding of how climbers will interact with quantified-self applications and what the individual requirements for such a system are.**

***Keywords*-information visualization; quantified-self; climbing; multi-device; sport**

I. Introduction

Various wearable sensors for sports like running, cycling or strength training are commercially available, which enable users to automatically record and track metrics related to the sport and physiological activity. Smartphone applications and web platforms provide access and visual representations of those detected data. The visual presentation and exploration of training data is important for the iterative process of self-reflection, motivation and change in user behaviours [1]. So far, consumer electronics, human-computer interaction and the visualisation of sensor data have paid very little attention to the increasingly popular and now widely enjoyed climbing sport. Climbing is a complex sequence of movements requiring different physical abilities such as coordination, muscular flexibility and physical strength as well as mental fortitude [2]. Novices usually learn climbing techniques in basic training courses. To continue improving their climbing techniques, most climbers are interested in self-assessment. However, common methods to track climbing training are limited to noting the climbed routes and their difficulty levels in books, spreadsheets or form-based smartphone apps. In 2013, the start-up ClimbAX utilised wrist-worn accelerometers to capture a climber's movement in naturalistic settings [3] and proposed some initial visual representations of the tracked data. Yet, for an effective self-assessment system, climbers additionally need contextual information such as route difficulty, training partners and motivation. Bridging this gap between sport-specific sensor data and contextual information, we conducted a design study resulting in a mobile application and a desktop analysis tool. Our goal is to support hobby climbers with a digital coach for self-assessment of climbing technique and physiological performance based on the data and sport-specific metrics provided by wrist-worn ClimbAX sensors [3]. For design and validation, we followed the nested model by Munzner [4] with its four levels domain situation, data/task abstraction, visual encoding/interaction idiom and algorithm: (1) Semi-structured interviews and a literature survey were conducted to understand the requirements of the climbing domain and find tools and applications in this research area. (2) These results were transformed to an abstraction of data and requirements. (3) The visualisation design was first developed in form of high-fidelity wireframes and evaluated by an expert review. (4) Key parts of the design were implemented in D3.js. As downstream validation this prototype was evaluated with target users in a usability study. As a design study [5], this work has contributions in characterizing and addressing the domain requirements of climbers such as multi-device support, manual input of contextual information and motivational feedback.

II. Related Work

Next, we survey existing work on tracking movement and contextual information in climbing, tracking other sports and visualization of tracked data. Up to now, little attention has been paid to tracking climbing movement and self-assessment. Previous research has concentrated on construction of sensor hardware and automatic extraction of movement metrics based on sensor data. ClimbAX [3] tracks climbs and scores the climbing technique. As it serves as data provider for this design study, its metrics will be described in more detail below. ClimbSense [6], in contrast, aims to automatically recognize climbed routes based on their wrist-worn device. Kalyanaraman et al. introduced another device that automatically tracks climbing routes using wearable sensors [7]. Additionally it infers hold types and monitors falls. A number of logbook applications are commercially available for climbers, which allow to manually track routes and other contextual information via an app, or analyse existing routes based on pictures from a route database [8], [9], [10], [11]. However, no application or research prototype is available serving climbers' need to track both technique metrics and contextual information. Overall, very little is known about specific requirements of climbers in terms of quantified-self applications for self-assessment. Self-assessment of technique and quality of movement based on wearable sensors has been explored in more depth for other sports such as swimming [12], [13], [14] or golf swings [15]. Also different commercial products like Fitbit, Jawbone UP, misfit Shine, Runtastic, Endomondo, FitBit, or Garmin track sports such as running, cycling, or strength training via wearable devices and provide native apps or web platforms for data. However, none of these systems support metrics for climbing. In terms of visualization of tracked data – either automatically or manually – bar charts, line plots, calendar views, pie charts and maps are most often used. Various applications also use tables to display performance data of an athlete. Sometimes unconventional visualisation techniques such as rings, buckets, or spiral timelines [16] are used in quantified-self applications. The initially proposed visual representations of ClimbAX data [3] are arranged in a multiple-view layout optimized for desktop usage.

III. Domain Problem Analysis

To identify the domain situation a problem characterisation and abstraction [5] was conducted including semi-structured interviews [17] and exploratory data analysis [18].

A. Data analysis

The ClimbAX system tracks every move and merges sequences of moves into climbs. For each climb, start and stop time as well as resting duration are recorded. ClimbAX evaluates the climbing technique (moves and holds) and reports the scores power, smoothness and stability [3] for each hand. In addition, a speed score and an overall score are included. All scores are given along a normalised 0–10 scale. The data is available in JSON. Abstracting the data along the categories of [19], the data can be characterised as time-oriented, multivariate and quantitative. Time is arranged linearly and the sequence of the climbing events can be organized by calendar granularity such as climbing days.

B. Semi-structured interviews

Procedure and study design: Five interviews were conducted from Feb. 9 to 13, 2015 at the therapeutical climbing centre in Weinburg, Lower Austria. Climbers aged from 14 to 44 years were interviewed. Each participant walked through the interview guideline containing questions relating to their usage and experience with tracking devices/applications, goal-setting and motivation and preferred devices and platforms. Other parts of the interview focused on familiarity with visualisation techniques and the existing visualisation dashboard of ClimbAX. The interviews took between 12 and 42 minutes and were recorded in audio and handwritten notes.

Results and discussion: Based on the contextual interviews three key requirements (R) were identified: **R1:** Provide a combination of a mobile application (overview of tracked data on the go) and a desktop application (detailed exploration and analysis) **R2:** Provide manual input possibilities for comments and daily conditions comparable to a physical logbook **R3:** Make use of tips and motivational message to give feedback. The analysis showed that two out of five interviewees use smartphone applications to track and log their physical activities of running and cycling, but none for tracking climbing activities. Paper calendars or notebooks are used to track their physical activities mainly noting altitude, distance, location and duration. Giving tips and providing forms of feedback by textual elements, highlighting of parameters or showing trends and patterns were identified as important elements in the motivation and self-reflection process. The following parameters were ranked as very important for performance measuring: number of moves, total session climb time, total session duration and number of climbed routes. Interviewees also suggested to provide the possibility to add notes and emotional information. The presented visualisation showing the balance between the left and right hand were ranked as very useful. Visualisation techniques known among the interviewees are standard business charts (line plot, bar chart, pie chart/donut chart, maps, calendar). The motivational aspect of sharing data [20] and [21] could not be confirmed based on the answers of the target group. E.g., participant 3 commented that *"[t]he sport is only for my wellbeing and I don't care about other athletes"*.

IV. Concept and Implementation

Our concept consists of a mobile web application and an interactive visual presentation and analysis tool. The mobile web application acts as digital logbook giving insights into today's training day. The web application gives users the possibility to perform deeper analysis (R1). To validate the concept, we developed a scenario-based prototype [22] based on HTML, CSS, JavaScript and D3.js.

A. Mobile web application

The mobile web application comprises a logbook and mobile analysis tool. The automatically collected data of the wrist-worn device formed the basis for the design. The need for recording and adding different contextual information was addressed in the form of manual input possibilities

(R2). In order to meet the need of climbers for getting tips and motivational messages (R3), in-application feedback was integrated. These messages notify users of substantial changes in their training activities and also call attention to changing parameters and performance data. The system is arranged based on the common *card layout* pattern [23, p. 526]. This concept of expanding cards is equivalent to the Overview First and Details on Demand idiom [24]. The colour scheme contains blue as primary colour for highlighting and red, light orange and cyan used to outline the metrics power, smoothness and stability.

The mobile application is based on a collection of well-established visualisation methods identified during the contextual interviews. The interface is separated in four areas (Figure 1). The first area combines a section for photographs or uploaded pictures and information such as date and location information. An aggregated score of today's climbing in comparison to the worst and best grade of the last training days is integrated into the header shown as horizontal bar chart comparable to a boxplot. Different messages based on the results of the climb act as motivational messages and a textual abstract of today's climbing performance. The navigation concept for browsing through the days of climbing is based on the mobile navigation pattern *page swiping* [25, p. 48] combined with small arrows as fallback buttons. In the second section, the user can enter contextual information such as climbing partner, category, and type of climbing to the climbing day by using standard input possibilities such as drop-down fields. Smiley icon buttons are available to set daily motivation quickly (R2). The third card contains a stacked bar chart representing detailed information related to climbed routes. Based on our interviews, this visualisation technique was found suitable for the target group and the given data. The number of bars represents the number of climbed routes in one particular session. The height of the bars encodes the total climbing time. The stacked element gives the user insight into total resting times in relation to the amount of time on the route. In this area the climbers can manually add comments and grades of climbed routes. The grade is not automatically tracked by the sensors, but it is an important parameter in the climbing sport, showing the complexity of the route. The need for adding comments to one route was as well identified in the interviews (R2). The fourth view displays the balance between right and left hand. The visualisation combines this data by using a table with two columns, one for the left and one for the right hand, and three rows mapping the three outlined metrics power, smoothness and stability. The climber's numerical score is qualitatively simplified and shown as one, two or three circles. This visualisation is based on the Gestalt laws of proximity and similarity [26]. Because of the importance of this aspect, messages which advise users of imbalances are integrated into the design. Critical parameters related to an imbalance between left and right hand are highlighted in

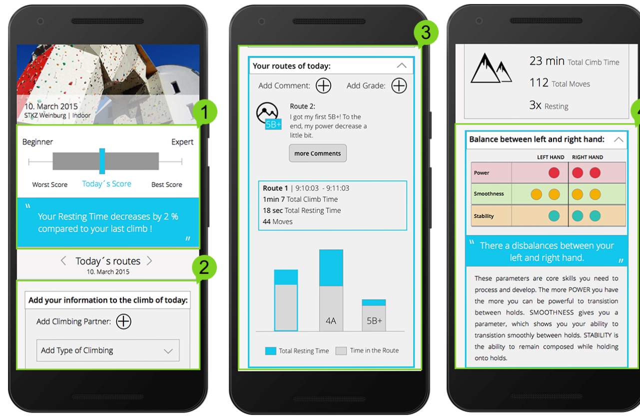

Figure 1. Mobile web application showing (1) spatio-temporal context and the overall score of a climbing day, (2) input for contextual training data, (3) details and comments on climbed routes, (4) balance between right and left hand.

the form of traffic light colours. Red signals an imbalance and the green balance between left and right. Furthermore, a description of the metrics is part of this section.

B. Interactive visualisation and analysis tool

The web application is a tool to analyse data in more detail and thus react with changes in the climbing training. The web interface is based on the visualisation techniques used in the mobile web application and complements those with more detailed visualisation techniques giving deeper insights into the tracked training data. All visualisation techniques were selected with the aim of providing an intuitive exploration.

The presented approach provides interaction possibilities for exploring large data spaces and find patterns in personal climbing training in multiple views [27] that show different aspects of the tracked data. Climbers can filter or navigate through the visualisation over time. The climbing score visualisation based on the mobile version is implemented in the interface on top seen on Figure 2.1. Key facts about the climbing day, such as number of routes, total climb time, moves and number of rests are positioned above the score visualisation. The motivational message is also part of the view. On the left, the input of users about climbing partner, type of climbing, category and the motivation collected via the mobile application are displayed. The stacked bar chart gives an overview of the climbed routes on one climbing day and is completed with the comment section, based on the input of the mobile device (Figure 2.2). The next area of the application gives climbers insights into detected imbalances between the left and right hand. Because of the importance of this topic the desktop application adapted the circle-based visualisation of the mobile app (Figure 1.4.) with a detailed view using horizontal bar charts. Bars are grouped by routes and follow the Gestalt law of symmetry [26]. Thus, the climber gains insights into the balances related

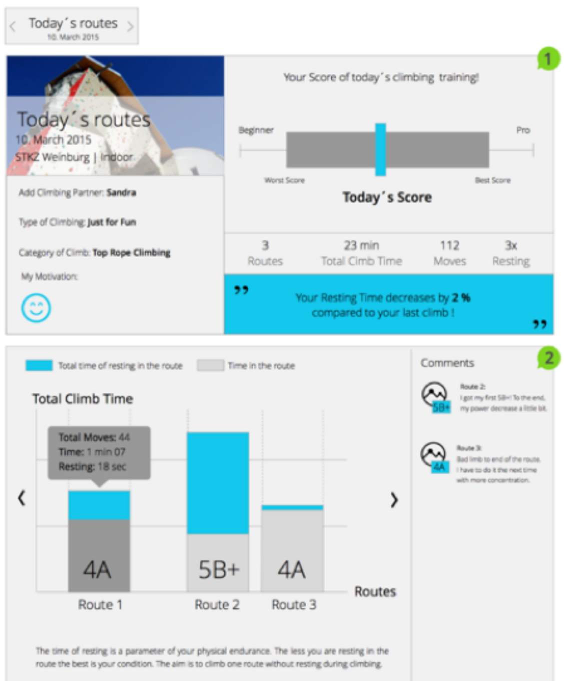

Figure 2. Analysis and presentation tool: (1) summary of climbing day, (2) climbed routes and comments to specific routes.

to specific routes. Filter possibilities are designed as icon buttons to reduce and display the specific parameter for both hands. Success of training can be analysed sufficiently after a couple of weeks. For that, we integrated an overview visualisation showing all manual and automatically tracked data in one view, providing the possibility to analyse the last trainings to draw conclusions from it. A well-known line plot and a bar chart (Figure 3) are integrated. The bars represent the number of climbs per day. By hovering over the visualisation, the climber gets information about the climbing day. The user can display or hide the trend line of each hand and parameter. Navigating and zooming in time by selecting a year, month or week view is also part of the interaction concept (Figure 3).

V. Evaluation

The visualization design in form of wireframes was tested with experts of different domains. The concept described above shows the revised version of the design. The revised concept was implemented as interactive prototype and was used for the usability study.

A. Expert review

Procedure and study design: The expert review was held in the form of interviews. The answers were documented via audio recording and written notes. Different paper prototypes (high-fidelity wireframes) were the basis for this. To show interactions and navigation actions, different screens were utilized. The experts analysed the wireframes based on one scenario for each device and usability metric: Consistency of elements, used visualisation techniques, wording, colour, used interaction techniques, navigation concepts, layout and simplicity. *Participants:* To cover domain expertise of human-computer interaction, visualisation and climbing, three experts were selected [17, p. 257]: Expert 1 is a male interface design and visualisation expert in quantified-self applications, who works as senior researcher associate at a university in the UK (E1). Expert 2 is a male expert in rock climbing, certified climbing instructor with 10 years' experience in climbing (E2). He works as a laboratory technician at a large industrial corporation in Austria. A female mobile interface design expert (E3), working as a researcher at a university in Austria completes the review participants. These three experts were chosen because of having years of experience in their fields and covering the relevant domain expertise for the developed system. *Results:* The following areas were improved in both systems as indicated by the expert reviewers: wording, colour usage, more interaction techniques and the visualisation for climbing score and balance between left and right hand. The used visualisation techniques on the mobile web application were found to be easy to understand and familiar by the target group. Also, the interaction concept was considered to be easy to use. The idea of giving the user automatically generated messages to provide a virtual training guide was discussed because of the design and utility of such motivational messages. E1 and E2 argued that the design and communication of such motivational feedback systems has to be very intelligent to be motivational for athletes. E3 categorised the idea of giving tips and motivational messages as important, especially for beginners. The used visualisation technique for showing imbalances was found to be very suitable. The overview

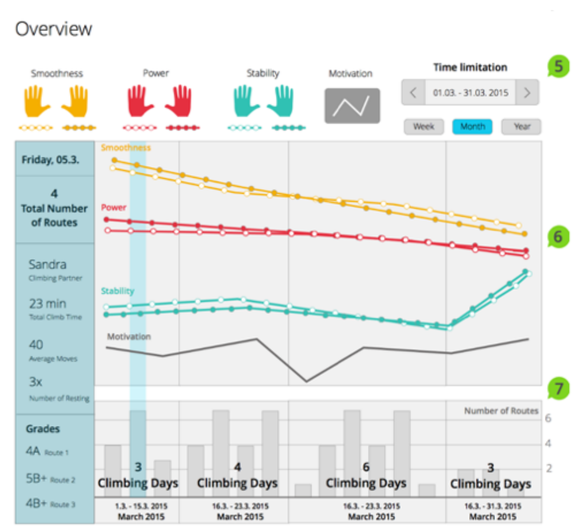

Figure 3. Overview: Identifying patterns and trends over one month of training by comparing all automatically and manually tracked data.

visualisation in the desktop web application was ranked as very useful for analysing the success of training.

B. Usability study

Procedure and study design: The implemented prototype formed the basis to explore usability issues in the particular domain of climbers. A qualitative observational usability study was performed to investigate when and why a visualisation technique works or does not work. This evaluation study should assess the strengths, weaknesses and limitations of visualisation and interaction techniques. The study was performed in a therapeutic climbing centre April, 13–14, 2015. Data was collected via direct observation and questionnaires [28, p. 418]. Video recording logged the interactions with the system and also the feedback of the subjects. During the direct observation handwritten notes were taken. Test devices were a Nexus 5 phone (Android 5.1) and a MacBook Pro 13 inches (OS X 10.9.5), both with a Chrome 42 web browser. Various tasks were defined for the prototype implementation. The participants were asked to speak out on their problems and needs while performing the tasks. In the last part of the usability study, a questionnaire was distributed. The introduction and the actual test took 20 minutes, and the questionnaire did not exceed 15 minutes. *Participants:* The target audience consisted of climbers of all ages, who are interested in new technological devices. The level of training or time since climbing was no exclusion criterion. Subjects were interested in new media and technologies but experiences related to the usage of quantified-self applications or systems were not required. Five climbers aged from 19–44 took part in the study (3 females and 2 males). *Results:* It is apparent that none of the subjects performed their interactions more often to achieve their goals. All interviewees categorised the tool as clean and understandable. The shown information, the combinations and used visualisation techniques were ranked as valuable. Moreover, the first impression of the mobile application and web application was positive. All participants categorised the interface as well-structured. Giving the user the possibility to add comments to individual routes was regarded as very useful features of the system. Tips integrated in the system were categorised as an excellent feature, which is especially attractive for beginners. The following suggestions for improvements to the interface of the mobile and web application design were given: (1) integrating a search functionality based on grades or names of route via the web application; (2) adding tips based on exercises improving strength and coordination; (3) providing an overview visualisation to show trends over a longer period: Show or hide parameters based on both hands, no splitting into of left and right hand (web application); (4) showing units of the trend lines of the parameters power, smoothness and stability (web application); (5) separating the motivation from the trend lines of the parameters in the overview visualisation (web application); and (6) adding filter possibilities related to indoor and outdoor climbing.

VI. Reflection and Conclusion

In this paper, a conceptual design and technical prototype were created to visualize data of wrist-worn sensors [3] and manual data input from a mobile web application. The developed system gives insights into training data and provides assessments of climbing training. The relevance of a quantified-self system for climbers is clearly supported by the current findings. The different validation steps confirmed that our system fulfills the requirements: **R1:** Provide a combination of a mobile application (overview of tracked data) and a desktop application (detailed exploration and analysis). In general, all interviewed participants of the study were willing to integrate the system into their climbing training. They indicated that the two systems are well-structured and easy to understand. Besides the given visualisation techniques and information, climbers suggested the need for providing more detailed information about breaks between climbs. Asking participants about their favourite visualisations of the mobile web application, the balance visualisation giving detailed information based on the climbed routes was favoured. The mobile device was identified as the preferred one. **R2:** Provide manual input possibilities for comments and daily conditions comparable to a physical logbook. The input possibility of information such as comments, grade, as well as a climbing partner was identified as useful by the target group. The used input methods in the form of text input fields were easy to use. *"The information input is very fast, only a few clicks and I am ready. I can imagine, that I will do the manual input when I am waiting for my climbing colleague."* (TP1) Climbers also stated that the information about climbing partner and daily condition can affect the daily climbing performance, making it important to manually track this information. Adding comments should give the climber the possibility to highlight special routes or save specific combinations of holds for the next training session. These manual inputs in combination with the automatically tracked information will replace the analogue notebook and calendar, participants of the study argued. **R3:** Make use of tips and motivational message to give feedback. Tips integrated in the system were categorised as an excellent feature, which is especially attractive for beginners. All participants addressed the design and content of the tip: *"The suggestions have to be designed to give examples of exercises improving the strength of hands and feet on the basis of sports science."* (TP3, TP4) Participants also mentioned the integration of heart rate measurement additionally to the information detected by the wrist-worn device due to its relevance in sport climbing and performance assessment. The findings provide an initial, empirically grounded understanding of how climbers interact with quantified-self applications and individual requirements for such systems. The motivational aspect of sharing data identified by Munson et al. [20] and Michie et al. [21] could not be confirmed in this study. Thus, the goal-setting and motivation within the context of climbing were defined as individual process of each climber. All subjects defined their goals based on climbing grades. In future studies, the effects of providing tips and motivational messages on climbers should be assessed. Moreover, further research on techniques beyond standard business charts with a more narrative character to visualize the detected data could be beneficial.

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