Mobile Application for Quantitative Climbing Level Assessment

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Abstract—**Climbing in general, and especially sport climbing, has become an increasingly popular recreational and competitive activity. Consequently, there are many climbers who would benefit from quantitative insight into their climbing level. After reviewing the research area and existing solutions, we found there are many climbing-specific measurement systems that allow acquisition of quantitative data, from which climbing level can be assessed. The vast majority of measurement systems of this type are scientifically oriented and therefore cannot be used by the general public. The motivation for our work was the development of a multi-purpose and portable climbing-specific prototype measuring system for obtaining quantitative force data with the use of upper limbs and a design of a mobile application for managing the measurements and presenting their results. The measurement systems offers force measurements for a variety of climbing-specific grips. Evaluation of the measuring system was performed with twelve subjects of diflerent climbing abilities. Within evaluation, we focussed on the user experience with the mobile application and on quantitative data obtained by the measuring system.**

I. INTRODUCTION

Climbing is an activity at which climbers move their body up a vertical terrain on a natural rock wall, on an indoor climbing wall or in the mountains. In recent decades climbing has become an increasingly popular activity. This is indicated by the fact that climbing was recognized as an Olympic sport for the first time at the 2021 Summer Olympics in Tokyo. The majority of time in climbing-specific training is dedicated to development of forearm muscles [1]. While ascending a climbing route on a steep face and griping different holds with a variety of grip techniques, forearm muscles hold climbers' weight on the vertical surface. Most common climbing grips are slope grip, open-crimp grip and closed-crimp grip [2]. Slope grip is used when climbers try to grip a round hold with no significant features. While using slope grip, the structures in the fingers are in most natural position. Therefore, injures are least common. Open-crimp grip is used on small ledges that can only support fingertips. Closed-crimp is a griping technique where climbers' hand is in the same position as in open-crimp grip. In addition, climbers put their thumb across pointer which increases friction between skin and the surface, enabling climbers to hold onto even the smallest holds [3, 4]. Closed-crimp grip is the most prone to pulley injury, followed by the open-crimp grip and slope grip [5]. The more forearm muscles are developed, the more difficult climbing routes (higher grade) one can climb. Consequently, the development of the forearm muscles directly corelates to ones' climbing level. The most common way climbers assess their climbing level is by climbing routes of a certain grade. The problem of assessing climbing level, based solely on the highest grade one could climb, is that all grades in climbing are subjective. This means that the assessment is not accurate and can be compared with others only to some extent. In contrast, an accurate climbing level assessment has many uses, some of which are: climbing progress assessment, assessment of rehabilitation process effectiveness of upper limbs, ranking of climbers, assessment of individual training session intensity. Our main goal is to develop a user friendly and versatile mobile application for quantitative climbing level assessment based on a grip force measurement system. In our work we address several important issues: (a) design and assembly of a measurement unit with force sensor [6] for grip force measurement, (b) the acquisition and processing of sensor signals, and (c) presenting the data in practical, understandable and easy-to-read way on an Android mobile device. With this measurement system the climbing level of climbers can be assessed in a quantitative way. Consequently, climbers or climbing coaches can get detailed and in-depth information of climbers' performance, endurance and strength [7].

II. MATERIALS AND METHODS

Measuring system consists of the following components: load bearing measuring unit with force sensor, professional measuring equipment for obtaining sensor signal, computer application for transferring measurement results to a cloud database and cloud database for saving measurement results with metadata. To enhance user experience an Android mobile application was developed where users can set and edit measurement metadata, create new subject, alter subjects data and view measurement results. Using above mentioned measuring system, along with the mobile application, a study was conducted.

A. *Load bearing measuring unit*

Load bearing measuring unit with force sensor is shown in Fig. 1. It has two basic parts: metal construction and sensor. A full-bridge strain gauge sensor (d) (Omega SGT-3G/350-FB11) is attached to the metal bar (b) 30 mm from the support plate (a) of the metal construction.

A triangle-shaped metal frame (c) allows subjects to use measuring unit with a variety of climbing grips.

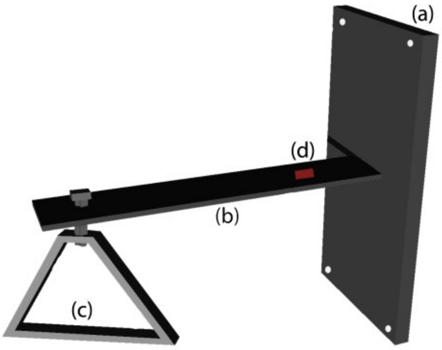


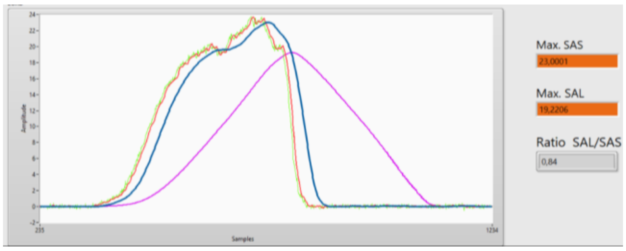
Figure 1. Load bearing measuring unit with force sensor. (a) Support plate, (b) metal bar, (c) triangle-shaped metal frame, (d) sensor position.

B. Professional measuring equipment

Measuring equipment consist of three parts: (a) industrial computer cRIO-9063, (b) bridge input module NI-9237 and (c) USB flash drive for local storage. Sensor is connected by a UTP cable to a bridge input module using RJ 50 connector. Sampling frequency f_s = 100 Hz was used. At the beginning of measurement process, sensor bias is calculated and then eliminated during the processing of sensor signal. Sensor bias is caused by temperature changes, measuring unit weight, position of the measuring unit and other influences. It is important to note that sensor bias has to be re-calculated if there is a change in any of the influences, in order to get accurate results. Butterworth filter (5th order) was used to minimize high frequency noise. Two averaging sliding windows of 50 samples (0.5 s) and 300 (3 s) samples were used in order to further resemble climbing. Resulting signal of the short averaging sliding window Signal Averaging Short (SAS) corelates to the shortest possible time to grip a hold while climbing or force impulsiveness. Resulting signal of the long averaging sliding window Signal Averaging Long (SAL) is to some extent corelated to the average time one grips a hold while climbing a route or force permanance. In practice that means, that the subject would have to hold a certain force for at least 0.5 s (SAS) or 3 s (SAL) to be recorded. Both averaging window lengths can be adjusted to specific needs of an individual. For example, if the subject is a speed climber, it would be reasonable to set shorter averaging windows than for a big-wall climber. For further analysis, the ratio between maximum values of SAS and SAL is calculated. Fig. 2. shows user interface of an application running on cRIO-9063. Application is operated through a laptop, where there is a special application for obtaining and transferring processed sensor signal to a cloud database.

C. Computer application

This Labview application transfers measurement results to a cloud database. The reason why data is not sent directly form the cRIO-9063 is that this specific device does not have the option to wirelessly connect to the Internet, which would present a problem on locations without access to wired internet connection. If the user of the measuring system is satisfied with the obtained signal, in-app button is pressed and the processed signal is sent to the cloud data base over HTTP POST along with metadata in a JSON format. After transfer, message appears in the Labview application that signals successful data transfer and storage.



Max. SAS
23,0001

Max. SAL
19,2206

Ratio SAL/SAS
0,84

Figure 2. Example of real time signal depiction on cRIO-9063 application. Green line: raw signal, red line: filtered signal, blue line: SAS, pink line: SAL. On the right hand side maximum values of SAS and SAL signal are shown in KG with calculated ratio between them.

D. Cloud Database

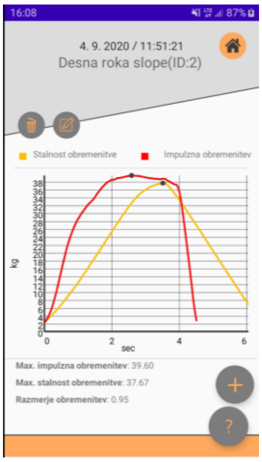
We choose Google Firebase, because it is easy to implement in both computer and mobile device. Cloud database consists of two basic parts. One is dedicated to subject data and partial measurement results for faster graphical rendering on mobile device. The other is dedicated for saving all measurement results along with corresponding metadata. Each measurement record holds three sets of data: (a) subjects' data, (b) measurement data and (c) measurement meta data. Subjects' data consists of subjects' name, climbing level, gender, age, weight, height and notes. Measurement data consists of raw signal, filtered signal, SAS, SAL, maximum values of SAS and SAL, ratio between maximum values of SAS and SAL. Measurement meta data consists of sensor bias value, scaling factor used and timestamp of measurement.

E. Mobile application

Mobile application named "hangON" was developed for Android operating system with versions above 8.0 (Oreo). Its purpose is to give user the ability to operate and control the measurement process and to view the measurement results and their analysis. In the measuring process, mobile application is first used when the name of the subject and measurement name are entered or chosen from the drop-down list. Conformation of names triggers cloud database to prepare for incoming data from the computer application. As soon as the storage process is completed, selected data is transferred to the Android mobile device and shown to the subject in an In addition, users can compare results of two measurements on the same screen, as seen in Fig. 4. Other functionalities include: editing name of measurement results, deleting measurement results, creating new subject, editing subjects' data and deleting subject.

F. Measurement process

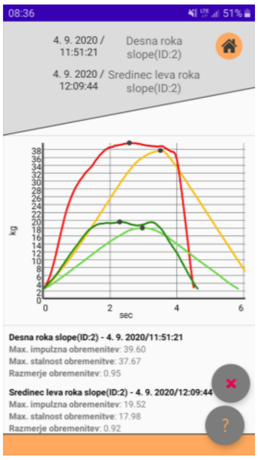
Measurement process shown in Fig. 5 starts on the mobile application (1) by entering the name of the subject and the measurement. This triggers cloud database to prepare fields for new set of measurement results (2). Then the acquisition of sensor signals is started through a computer application (3). Next, the subject generates force by pressing downwards on the underside of the metal triangle that is part of the measuring unit, in a desired hand position (4). After subject stops generating force, user stops the signal acquisition (5). Then, measurement results are automatically transferred into the computer application where they are formatted and sent to cloud database (6). In the cloud database measurement results are processed before saving (7). Finally, results are sent to the mobile application display (8). Note that this is a prototype. The goal is to make a measuring unit that would be integrated into a small device with direct communication to the mobile application that would implement the functionalities of entities (b) and (c).



4. 9. 2020 / 11:51:21
Desna roka slope(ID:2)

Max. impulzna obremenitev: 39.60
Max. stalnost obremenitve: 37.67
Razmerje obremenitev: 0.95

Figure 3. Results of one measurement in the mobile application. On the top of the screen there is a timestamp, below is a name of the measurement and ID. Two buttons (top left side) allow user to delete or edit presented measurements' data. The graph shows the processed signal SAS (red) and SAL (yellow) with their maximal values at the bottom. With the "plus" button, another measurement result can be added on the same screen.



4. 9. 2020 / 11:51:21 Desna roka slope(ID:2)
4. 9. 2020 / 12:09:44 Sredinec leva roka slope(ID:2)

Desna roka slope(ID:2) - 4. 9. 2020/11:51:21
Max. impulzna obremenitev: 39.60
Max. stalnost obremenitve: 37.67
Razmerje obremenitev: 0.95

Sredinec leva roka slope(ID:2) - 4. 9. 2020/12:09:44
Max. impulzna obremenitev: 19.52
Max. stalnost obremenitve: 17.98
Razmerje obremenitev: 0.92

Figure 4. Results of two measurements presented to the user in the mobile application. Red and yellow lines represent SAS and SAL from first measurement result, respectively. Dark and light green lines represent the same data from the second measurement result. At the bottom, maximum values of both SAS and SAL are shown along with their ratio for both measurement results. User can return to viewing one measurement result by clicking the button with a red cross.

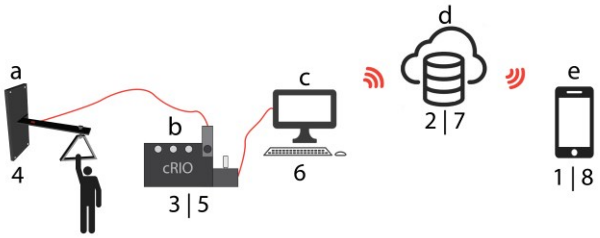


Figure 5. Measurement system architecture: (a) load bearing measuring unit with force sensor, (b) professional measurement equipment for obtaining sensor signal, (c) computer application for transferring measurement results to cloud database, (d) cloud database, (e) mobile application. The numbers below the entities denote the order in which they are used during a measurement process.

G. Study

The purpose of this study is to test the user experience and the usability of our measuring system in producing useful quantitative data in the context of climbing specific grip force measurement. The study was divided into two parts. In the first part we focused on user experience and in the second part, focus was on the usability of quantitative measurement results. The first part included 12 climbers of different climbing abilities that were divided into pairs. Eight of them were beginners with climbing level lower than FA 6a; and four were advanced climbers with climbing level higher than FA 7b and lower than FA 8a. One pair member was operating mobile application and application for obtaining sensor signal on cRIO-9063. The other pair member was the subject and was responsible to generate force for 3 s on the measuring unit. After completing a set of measurements, the roles were switched. With each pair we started the experiment with an introduction where we described tasks of each pair member in detail. Position of the subject (see Fig. 6) was shown and we did up to three trial measurements in order for the pair to get comfortable in their roles.

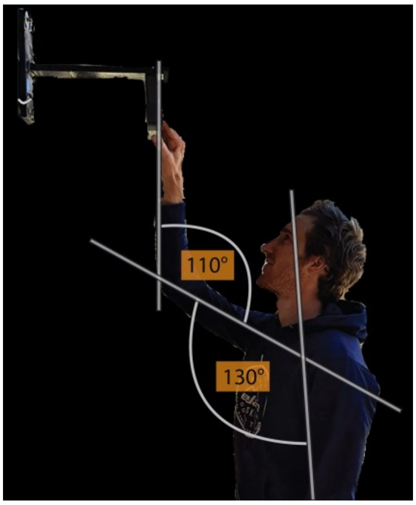


Figure 6. Position of the subject during measurements. Upper arm at 130° according to the body, forearm at 110° according to upper arm and wrist extended.

Next, a warm up consisting of general whole-body exercises and climbing specific exercises was done by the subject. Measurements were done in slope grip and open-crimp grip. We avoided closed-crimp grip to avoid injuries. One set of measurements consisted of 20 separate hand positions, including: both hands in slope grip and open-crimp grip and each finger (excluding thumb) on right and left hand in slope and open-crimp grip, as shown in Fig. 7. During the measurement process the operator of the applications guided the subject through all of the 20 different hand positions that were pre-added in mobile application. The main task of the operator was to choose and confirm the appropriate name of the subject and name of the measurement on mobile application and then start the obtaining of the sensor through a lap-top. If the measurement was successful, operator confirmed it with an in-app button and the results were sent to cloud database. In a few seconds results were shown on mobile application which marked the end of one measurement.

Figure 7. Conducting measurement with whole-hand open-crimp grip (left) and middle finger open-crimp grip (right).

The second part of this study was conducted with one advanced climber (climbing level FA 8a) through three climbing specific trainings during a five-day timeframe. Measurements were made before and after each training session. The goal was to determine the effect of each individual session on subjects' grip strength as well as effect of the combination of this specific training sessions. Slope grip and open-crimp grip on both hands measurement set consisted of 4 separate 3 s measurements done with the maximum effort. All the measurements were done twice with a 2 min rest in-between measurements. Better result was used in the analysis. Training sessions were done on Monday, Wednesday and Friday. Monday training session included lead climbing (climbing on a high indoor climbing wall with a rope). Subject climbed 10 routes up to FA 8a, excluding warmup routes. On Wednesday subject did a bouldering session (up to 5 m tall indoor climbing wall that is climbed without a rope, but with mats that soften the fall). Subject did 11 maximum effort attempts on boulder problems with grades up to FA 7A. On Friday subject did a training session on campus board (usually about 3-4 m tall and slightly overhanging wooden plate with different griping options that climbers ascend without using their feet).

III. RESULTS AND DISCUSSION

Results are divided into two sections: evaluation of the user experience of measuring system and gathering quantitative results of the study.

A. User Experience

In general, responses were very positive. For the first time climbers that have taken part in this study, had the opportunity of in-depth insight of forces they were generating during climbing in a variety of climbing specific grip techniques. Many of the participants were eager to do more measurements once the study was finished. During the first measurements, operators of applications on Android mobile device and laptop had some troubles with the user interface. Extra explanation was needed for the operators to fluently use the applications. Mobile application should, therefore, include detailed instructions of its functions. Many times measurements were repeated due to either subjects' or operators' mistake in the process. In that case operator had to manually return to the home screen of mobile application and repeat the whole process of choosing and confirming name of the subject and name of the measurement. To avoid this, an extra in-app button should be implemented on the screen where results are shown. That way operator could just re-start the measurement with the same attributes. At the end of the first part of the study, participants wanted to know how their results compare to others. While it is possible to go through all the results manually and compare two individual results, it is in this case very ineffective. Implementation of a list of measurement results with the option to sort by different attributes, would resolve this problem. Also, the possibility to export results in some of the widely used formats (e. g. pdf) was mentioned by some participants. That would be specially useful if the measurement system would be used by climbing team coaches. During the first part of the study, many participants felt that it would be easier to operate the application on a bigger screen. As the application would encompass more functionalities it would be wise to implement it as a web application. That way it could be used on any smart device, regardless of operating system.

Subjects that are advanced climbers expressed interest towards having the option to swich metal triangle-shaped hold with a variety of climbing holds. Not only that the option to measure gripping force with different climbing holds would increase the number of gripping techniques that could be used in measurements, measurements would also better resemble the actual climbing conditions.

B. Quantitative results analysis

All quantitative results presented below show SAS. In this study, we did not use SAL due to lack of climbers with approximately the same climbing level and of same climbing discipline. As mentioned, SAL shows force permanence which to some extent corelates to ones' endurance. Between climbing disciplines (lead, speed, bouldering, mountain climbing) endurance of climbers largely differs. Therefore, it would be very difficult to set correct time for averaging window that would encompass all disciplines.

It was expected that the subject would generate the highest load on Monday (52.53 kg, right hand, slope grip) before the training session and the lowest on Friday (18.35 kg, left hand, slope grip) after the training session. Monday's lead climbing measurement results are presented in Table I. It can be clearly seen that subject was tired after training. This is indicated by the sum of differences (42.91 kg). On Tuesday and Thursday subject had a complete rest from training. Measurement results from Wednesday bouldering are shown in Table II, they indicate that the subject was well rested before training session, but more tired after it as results are considerably lower with the sum of differences at 57.51 kg. Measurement results from the Friday's campus board climbing are presented in Table III. It is clear that the rest day had not been enough for the subject to regain full strength compared to the results from Monday session. Even though the sum of differences on Friday (54.49 kg) is lower compared to the sum of differences on Wednesday, it is clear by comparing the tables II and III, that the subject was more tired on Friday. This specific training regime had the least effect (least tired) on subjects' right hand in open-crimp grip position (difference between first and last measurement result is 23.35 kg). The most effect (most tired) proved to be the left hand in slope grip position (difference between first and last measurement result is 31.73 kg). This is directly corelated to the fact that it is harder to maintain consistent load bearing in slope grip than in (open) crimp grip. The reason for that is the friction between pulley and facia which is not present in slope grip [8, 9].

TABLE I
MONDAY MEASUREMENTS (LEAD)

Grip	Before	After	Diff.
Slope grip – R hand	52.53	43.53	9.00
Slope grip – L hand	50.08	37.44	12.64
Crimp grip – R hand	48.70	37.80	10.89
Crimp grip – L hand	46.25	35.86	10.38
		SUM:	42.91

TABLE II
WEDNESDAY MEASUREMENTS (BOULDERING)

Grip	Before	After	Diff.
Slope grip – R hand	52.21	30.36	21.84
Slope grip – L hand	52.00	40.38	11.62
Crimp grip – R hand	46.50	34.54	11.96
Crimp grip – L hand	48.84	36.76	12.08
		SUM:	57.51

TABLE III
FRIDAY MEASUREMENTS (CAMPUS)

Grip	Before	After	Diff.
Slope grip – R hand	33.57	25.17	8.39
Slope grip – L hand	35.12	18.35	16.76
Crimp grip – R hand	40.02	25.34	14.67
Crimp grip – L hand	33.79	19.14	14.65
		SUM:	54.49

IV. CONCLUSION

The constant quantitative evaluation of climbing level has many advantages. The developed system offers detailed information about climbers' endurance level and strength in both hands, one hand or even one finger in a variety of grip techniques used in climbing. Consequently, climbers can adjust their training according to the measurement results and progress rapidly. During the process of assembling the measuring unit and implementing functionalities into mobile application it would be reasonable to include more end-users. Consequently, we would be able to implement functionalities that were mentioned by test subjects in evalvation of the user experience. The main goal for future work is to upgrade mobile application to the point where it encompasses the functionalities from both computer application and application on cRIO-9063. That includes replacing cRIO-9063 with a specialy made device that would be small enough to be attached to the measuring unit. That would have significant beneficial effect on transportability and usability of the system.

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