ClimBSN: Climber Performance Monitoring with BSN

Julien Pansiot, Rachel C. King, Douglas G. McIlwraith, Benny P. L. Lo and Guang-Zhong Yang

Abstract— **The recent growth in popularity in sport climbing is partly due to the safe environment provided by indoor climbing walls, particularly for novice climbers. Sport climbing involves a wide range of skills and abilities. The purpose of this paper is to present a wearable sensing platform and an analysis framework for assessing general climbing performance during training. To provide the required freedom of movement, a single miniaturized ear-worn 3D accelerometer-based sensor is used. Independent features derived from the accelerometer data are then translated into climbing-specific measures, such as motion fluidity, strength, as well as endurance. Based on these indices, the overall level of the climber and the associated climbing styles can be quantified.**

***Keywords*: sport-climbing, body sensor network, sport monitoring**

I. Introduction And Related Work

Sport climbing has become increasingly popular internationally during the last two decades [1]. Indoor sport climbing can be practiced almost at any level with novice climbers naturally and progressively increasing their abilities. Due to the complex maneuvers and mental engagement involved, beginners are often unaware of some particular climbing aspects, such as the importance of footwork. In this study, we show that an easy-to-use, wearable and non-intrusive sensor platform can provide useful insight into a climber's technique.

The technical level of sport climbing routes is usually classified using an one-dimensional grade. Commonly used grades include the Yosemite Decimal System (YDS), the French and British systems [2]. The French and British grades use increasing alpha-numeric levels, for example 4a, 4b, 4c, 5a, 5b, 5c, 6a, 6b, 6c, etc. In practice, the difficulty of a route is subjective and composed of several independent characteristics, dependending on the abilities of the climber. They include:

- the type of holds (e.g. size, shape, friction, ...)
- the spatial relation between holds
- the inclination of the route
- the length of the route
- the exposure

For example, a route graded as (5b) could potentially be composed of a sparse distribution of comfortable holds or a more dense coverage of slippery holds, as illustrated in

Fig. 1. Two different climbing routes for the same grade (5b), where the black disks highlight composing holds. The route on the left consists of less holds, but they are generally more comfortable.

Figure 1. These two routes involve different abilities. In an effort to convey more information than the one-dimensional grading system used, most climbing guide books provide an evaluation of these characteristics as well.

The ability of a climber to succeed on a given route is therefore inherent to a large variety of physiologic and anthropometric factors, as well as skills acquired during training. These include hand grip strength, strength-to-weight ratio, power, hip flexibility, endurance, body fat percentage, stature, confidence and route planning [3]-[6].

Most rock-climbing studies rely on complex equipment, and thus are not suitable for the recreational climbers. In this study, we aim to demonstrate the difference in technique between different climbers on a given route and the difference in style for a given climber using a lightweight, easy-to-use device based on BSN technology. To our knowledge, only one similar wearable climbing monitoring system has been developed to date, which relies on a network of ten accelerometers distributed on the body [7]. The climber's energy expenditure is derived from each sensor, providing an estimation of the motion fluidity. No

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information was given with respect to the sensor fusion method, nor any comparative result.

The rest of this article is organised as follows. Section II introduces our system design, Section III describes the experiment carried out to validate our system, whilst Section IV details the data processing steps. Finally, Section V summarises the results of this experiment and Section VI concludes and propose future extensions.

II. System Design

A single ear-worn activity recognition (e-AR) sensor, depicted in Figure 2 is used in this study. This is a miniaturized version of the e-AR sensor initially proposed by Lo et al. [8] [9]. The system uses a Nordic nRF24E1 chipset with built-in 2.4GHz RF transceiver, memory, and an analog-digital converter to retrieve data from a 3-axis accelerometer. Due to its small size and unobtrusive positioning of the sensor, it is well-suited for monitoring climbers. The climbers wear the e-AR sensor during their ascents whilst a receiver records wirelessly the corresponding motion data on the ground.

Fig. 2. Left: the e-AR sensor used in this study. Right: a climber during the experiment.

III. Experiment Design

To evaluate the use of the e-AR sensor to monitor sport-climbing, experiments consisting of three phases were carried out: pre-assessment, attempts of increasingly difficult routes, and multiple ascents of the same route in quick succession.

Physiological measurements were taken for each participant prior to climbing data recording. These provide a recognized and standard set of measurements with which to describe the overall abilities of the participants:

- Body weight
- Maximum hand grip force: a hand grip dynamometer [10] was used to measure the isometric contraction of the fingers
- Core and arms endurance: measured as the time during which the user can hold the “plank” position
- Strength-to-weight ratio can then be derived from these measurements

A subjective self-assessment was also performed: each subject was asked about his general exercise volume (none, low, medium, high), climbing experience (none, little, intermediate, advanced) and the hardest route level consistently and successfully climbed (3a to 6c). The subjects taking part in the experiments had different skills levels as well as varying general strength, as summarized in Table I.

TABLE I
Climbers pre-assessment summary

	General activity level	Climbing level	Strength-to-weight ratio	Endurance factor (s)
Climber 1	low	5b	0.68	132
Climber 2	high	6a	0.86	190
Climber 3	medium	6b/6c	0.70	130
Climber 4	high	6b/6c	0.75	200

The second part of the experiment was designed to capture the general climber's abilities. It consists of ascent attempts on four 9-meter-high, indoor artificial vertical climbing routes. Top rope belaying technique [2] was used since it maximizes the climber's safety and no equipment-specific technique is required. As a result, this reduces the experiment variability due to anchoring techniques, confidence and route planning.

Four subjects were asked to attempt a climb on a set of routes of increasing grades: 3c, 4b, 5b and 6a. A resting time of five minutes was given to them in-between attempts. This increase serves a dual purpose: firstly to collect data demonstrating the difference in climbing style with varying difficulty, secondly to assign a reference level to each climber at the time of the experiment. This level corresponds to the last route finished. The subjects were asked to use only a given colored set of holds with their hands and feet, however, some of them unavoidably used their feet directly on the wall in difficult situations, making their ascent easier.

Only the start and the end of the ascents were marked. No attempt was made to further segment the data into phases such as resting, climbing or falling, as in [7].

The third part of this experiment was focused on endurance and route learning. Each subject was asked to climb five times consecutively the same easy route, graded 3c. Between five and ten seconds of rest were taken while the climbers are being lowered to the ground, but no further rest was allowed to the climber. Several factors can influence the climbing motion and they include: increasing confidence; decreasing route planning time; and decreasing force relative to the endurance factor. In general, the two first aspects lead to increasing the speed, whereas the latter slows down the climber.

IV. Feature Generation

Raw 3D acceleration data collected shows climber dependent patterns, as illustrated in Figure 3. In order to reduce the data dimension, several climbing metrics were extracted. The raw 3D acceleration is re-sampled at 200Hz and smoothed with a 50ms square window. After sensor calibration, the overall climber acceleration is computed by offsetting the acceleration due to gravity and normalized to 1, as in [7].

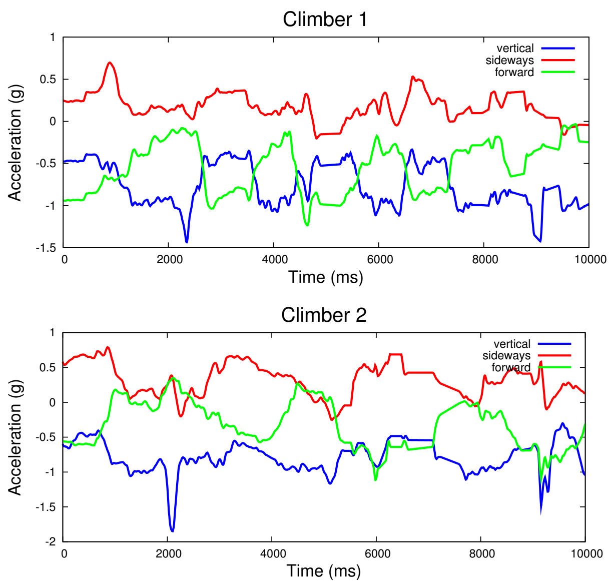

Fig. 3. Raw 3D acceleration of two climbers on the same route. Note the difference in style.

An estimation climber's head tilt can be derived from the 3D inertial sensor. This provides a good insight of the overall climbing posture. The fluidity of the motion can also be estimated from the jerk (sometimes referred to as jolt), which is defined as the third order derivative of the position. In order to reduce the dimensionality of the smoothed acceleration whilst preserving its meaning, several scalar features were also extracted for each ascent. These lead to a total of 27 features per ascent and include:

- Time to climb route
- Mean and standard deviation of the acceleration in each direction; the overall acceleration; and the head tilts
- Trends of the previous features: differences of means and standard deviations between the second and the first half of the ascent
- Mean of the jerk
- Jerk mean trend

V. Results

A. *Direct Features Interpretation*

It has been observed that some features are tightly related to climbing abilities and can therefore be interpreted directly from the graphs. It has been shown that good climbing technique uses efficient, energy saving movements. This involves using leg power where possible and reserving upper body strength [1], [2]. Therefore, poor climbing technique is often compensated by an overuse of strength on easy routes. The standard deviation of the overall acceleration appears to be the best indicator of this phenomenon. Indeed, this feature is mainly affected by intense movements. The climber's strength-to-weight ratio shows a linear relationship with the acceleration standard deviation, and can be modeled by this single feature with a RMS as low as 1% on middle range routes.

During the third part of the experiment, the climbers were asked to climb successively the same easy route five times. Most climbers get faster for each successive ascent. This demonstrates that route planning becomes less of a factor over the ascents, reducing the required time. Novice climber 1 had to stop after four ascents. The average jerk over the ascent captures the high-frequency shaking motion associated with tiredness of the climber, and therefore is a good indicator of endurance. Figure 4 illustrates the increasing jerk with the successive ascents. A limitation of this feature can be seen for Climber 1. This climber was resting a lot in static positions on the wall, and thus causing a lower value of average jerk.

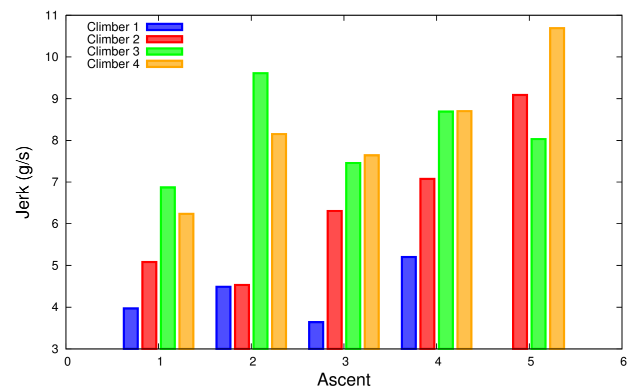

Fig. 4. Average jerk on the same route successively climbed up to five times. Increasing jerk is a sign of tiredness.

B. *Overall Style*

In order to better visualize the intrinsic signal patterns, the most discriminative features are then isolated using Principal Component Analysis (PCA). As expected, the climbing time plays a major role in the analysis: this is an obvious measurement of the climber's ability on a given route.

The climbing time was then removed from the feature set, in order to isolate the climbing style from the speed. 19 ascents performed by 4 climbers were re-projected on the first three principal components. Gaussian Mixture Models (GMM) were then fitted to the data using an unsupervised Expectation-Maximisation (EM) algorithm. This classifier distinguishes well between the climbers: only 2 ascents are misclassified out of a total of 19. Climber points tend to cluster, demonstrating a distinct style, as illustrated in Figure 5.

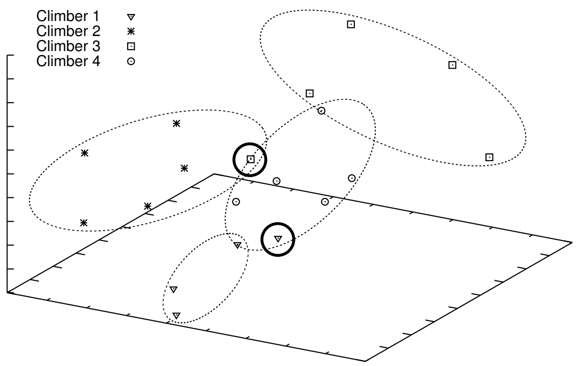

Fig. 5. PCA applied to the feature sets of four climbers ascending the same route several times. The style of the climbers is modeled by GMM using the EM algorithm. The axes mainly reflect the jerk and its trend as well as the accelerations means and standard deviations. Point clusters demonstrate distinct climbing styles. Bold circles denote misclassified ascents. Following previous interpretations, the vertical axis is related to the overall level, whereas the horizontal ones are related to fluidity and strength.

C. Climbing Profile

Direct features reading and reduced feature set can provide a detailed insight on the climbers motion but this operation is strenuous, and not ideal for recreational climbers.

Information inherent to the feature set needs to be interpreted in terms of climbing abilities. Four abilities are considered in this study: fluidity, speed, potential strength-to-weight ratio and endurance. We aim to provide a set of scores to the user depending on his/her ability.

The main features identified through PCA are mapped to the abilities scores. While the actual mapping is certainly not linear for all features, this provides reasonable results in the training range of our initial study. The mapping matrix was computed using a least square approximation on a reference set. Strength-to-weight ratio and endurance references are provided by the pre-assessment data, speed reference is based on a single measurement on an easy route (3c) and fluidity reference is assessed visually. A climbing profile based on the ability scores is then presented using polar graphs, as illustrated in Figure 6.

VI. Conclusion And Future Work

In this paper we demonstrate the use of miniaturized e-AR sensor for deriving different performance indices of recreational climbers. It has been shown that the system is easy to use and the signal derived correlates well with the overall technical ability of the climber. The use of PCA combined with GMM clustering, the progression of the performance indices due to training can be assessed. A larger dataset would be necessary in future studies to examine the long-term progress of the climber both in in-door and out-door environments.

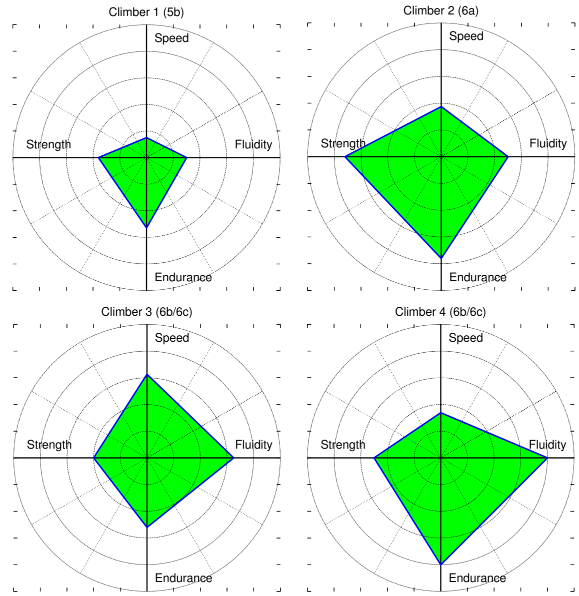

Fig. 6. Climbing profile graphs of the four climbers presented in Table I. Each ability (fluidity, speed, strength-to-weight ratio and endurance) is scored along an axis, better scores being further away from the centre.

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