Smart Belay Device for Sport Climbing
An analysis about falling and the importance of belaying

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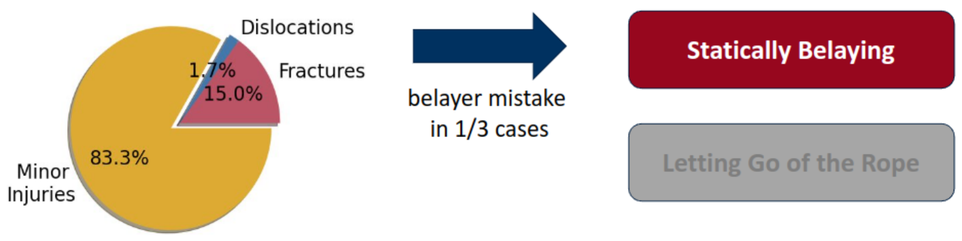
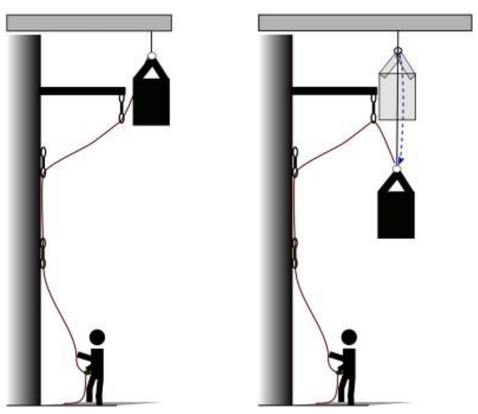
Introduction



Indoor sport climbing is a relatively safe sport as a 5 year long study in a climbing gym in Stuttgart, Germany by Schöffl et al. [1] revealed. They recorded an injury rate of 0.02 injuries per 1000 hours of climbing which is less than in walking (0.15-0.25) or Golf (0.07-1.12) [2]. Though, if a mistake is done while climbing, the injuries can be severe. The same study by Schöffl et al. revelead, that from 16 lead climbing injuries, 3 led to a permanent disability and 5 to a fracture. Another study by Luiggi et al. [3] came to the same conclusion. They did a survey on 3919 climber and found out, that in 16.7% of treated climbing injuries in emergency departments were severe injuries like fractures or dislocations.
In the study by Schöffl et al., 10 out of the 16 injuries were attributed to a mistake made by the belayer. The identification of belaying mistakes was also drawn as a conclusion in the study by Luiggi et al. In their study, the belayer was responsible for one out of three injuries. One of the reasons was the static belaying of the belayer.
This is where our reasearch connects. We integrated multiple sensors into a belay device and recorded climbing ascents and falls. This allowed us to extract meaningful key parameter from the climbing sport and prepare them for the end user.

Data Acquisition

Climbing Falls

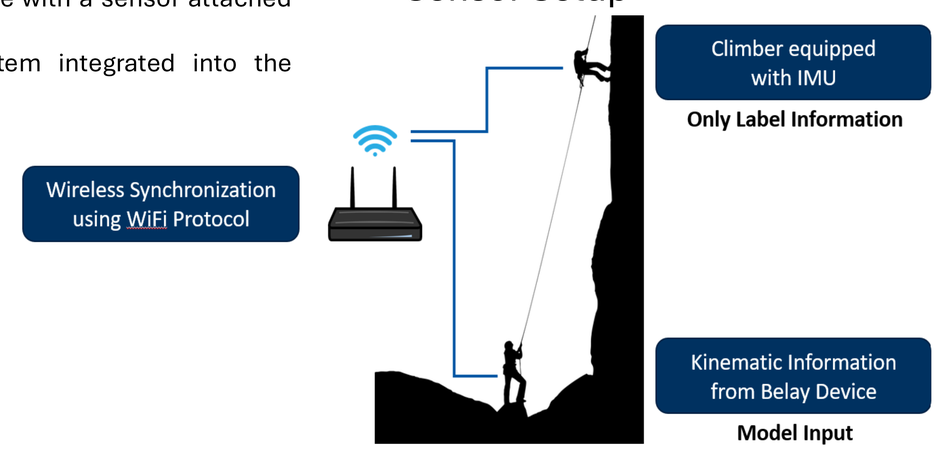


Climbing Ascent

Training Setup: a system that connects the instrumented belay device with a sensor attached to the climber
Final Setup: Soleil system integrated into the belay device

Climbing Falls: Isolated falls with different configurations (fall height, slack, dynamic & non-dynamic belaying)
Climbing Ascent: Lead climbing with different configurations (clipping position, slack, active & passive belaying

Sensor Setup



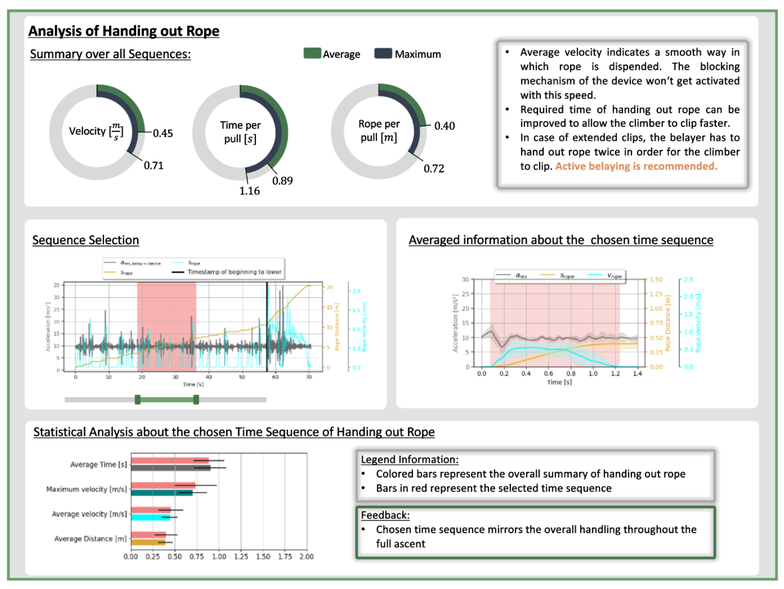
Data Analysis

We are able to extract and estimate several key factors for sport climbing. Some, like the lowering speed or the velocity of handing out rope can be directly extracted using the belay device. Others have to be estimated using complex computer algorithms. Among them, is the identification of a fall into the rope, the associated impact force or the height and duration of the fall. Another important key factor is the analysis of the type of belaying. Using the device, we were able to identify how the belayer behaved during the fall. The following three parts cover several areas in the form of a dashboard.

Analysis 1: Summary of the ascent & falls

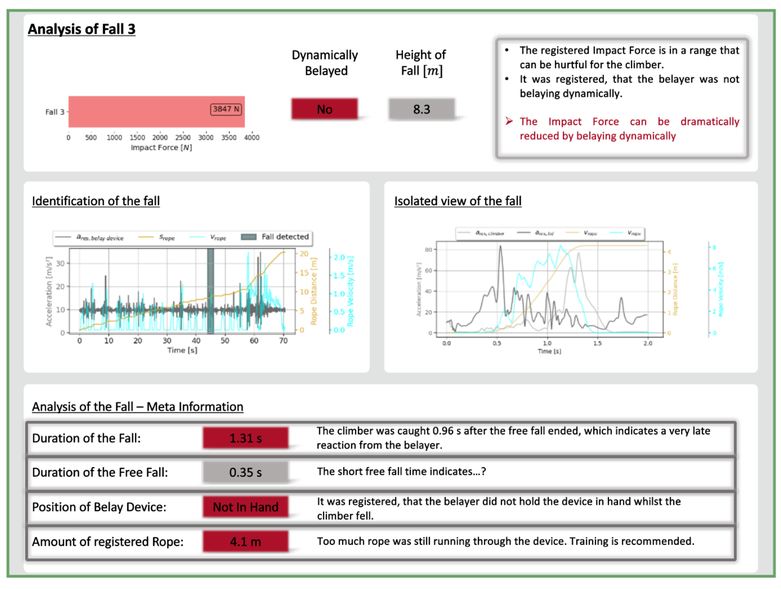
It provides an overview about the ascent, counts the amount of falls and categorizes their severity. The lowering of the climber is covered here as well.

Analysis 2: Feedback about the ascent



Certain timespans can be selected for a deeper analysis of how the belayer was handling the rope. It provides a statistical comparison against the extracted information from the full ascent. All of those information can be directly extracted from the instrumented belay device.

Analysis 3: Feedback about the falls



The fall is highlighted within the ascent at the time of occurence. Additionally, the sequence of the fall is prepared in a separate graph. It visualizes the timeline of the selected fall including the velocity and distance the rope has traveled. The remaining key parameter indicate the severity of the fall.

Estimation and prediction of the key parameter

The main focus was to use the belay device without any sensors attached to the climber. Therefore, some key paramteter have to be estimated or predicted like the identification of the fall, the impact force and the type of belaying. Another focus was to use this system in a real time environment to directly use it in the situation of a climbers fall. Therefore, it required to be fast in the prediction of a fall without sending a false alarm. We were able to identify a fall on average 0.27 s after occurence whilst having a false alarm only once in every 9th sport climbing route.
The impact force is a key parameter in estimating the severity of a climbers fall into the rope. Using the belay device alone, we were able to estimate the impact force correctly with an average error of about 0.3%. In the same way, we were able to differentiate between dynamic and non-dynamic belaying with a certainty of around 93.18%.

Fall Identification Time:	False Positives Falls:	Impact Force Estimation Error:	Dynamic vs Non-Dynamic:
0.27 s	**Once every 9th Route**	**0.3%**	**93.18%**

[1] Schöffl VR, Hoffmann G, Küpper T. Acute injury risk and severity in indoor climbing-a prospective analysis of 515,337 indoor climbing wall visits in 5 years. *Wilderness Environ Med*. 2013;24(3):187-194. doi:10.1016/j.wem.2013.03.020
[2] Parkkari J, Kannus P, Natri A, et al. Active living and injury risk. Int J Sports Med. 2004;25(3):209-216. doi:10.1055/s-2004-819935
[3] Luiggi M, Lafaye P, Martha C. Epidemiology of sport climbing injuries caused by a climbing fall among climbers of the French Federation of Mountain and Climbing. *J Sports Med Phys Fitness*. 2023;63(3):452-460. doi:10.23736/S0022-4707.22.14388-4

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