# Augmented Climbing: Interacting With Projected Graphics on a Climbing Wall

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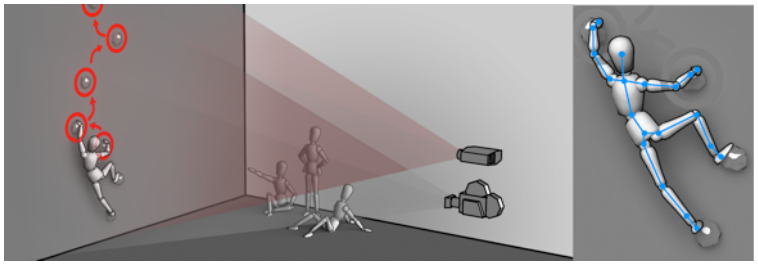

**Figure 1**. The augmented climbing wall concept with projected graphics and body tracking for interaction and augmented feedback.



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## Abstract
This paper describes our efforts in developing a novel augmented climbing wall. Our system combines projected graphics on an artificial climbing wall and body tracking using computer vision technology. The system is intended for accelerating motor skill learning or to make monotonous parts of the training fun by adding relevant goals and encouraging social collaboration. We describe six initial prototypes and the feedback obtained from testing them with intermediate and experienced climbers.

## Author Keywords
Computer vision; rock climbing; exergames; exertion interfaces; augmented feedback;

## ACM Classification Keywords
H5.1 [Information interfaces and presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities

## Introduction
Climbing has become a popular sport in recent years. It is performed outdoors as well as indoors where artificial climbing walls are used in training and the sport can be performed year-round in a dry and relatively safe environment. Improving one's performance in all sports, as well as in climbing, includes improving in

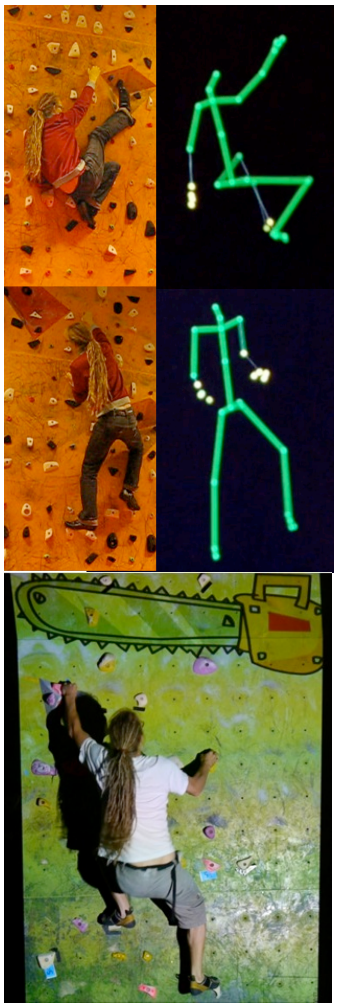

**Figure 2** Photos from our feasibility studies. Top: Inaccuracy of Kinect v2 skeletal tracking. Bottom: Animated saw chasing the climber.

motor skills, strength, endurance, knowledge, etc. Learning a new skill, building strength or endurance often includes many repetitions before the desired level is reached. This is often a time consuming and strenuous process. Fortunately, technology can make training less agonizing, e.g., by making the repetition and learning cycle faster, increasing the motivation to exercise actively or to perform monotonous exercises.

In this paper we describe our efforts to create an augmented climbing wall for bouldering, illustrated in Figure 1. Bouldering is a style of climbing performed near the ground, without ropes and harnesses, but over mattresses that catch the fall. The augmented climbing wall consist of a projector, a depth camera, and a computer system for analyzing climbers movements, providing feedback about the climbers' performance or creating meaningful tasks for the climber. We describe a feasibility study and a user study for providing understanding what kind of human computer interaction (HCI) is possible or desirable while climbing.

## Related Work and Motivation

There has been a substantial amount of research concerning climbing. However, the studies have concentrated mostly on the physiological aspects of climbing [2, 9, 15]. Also the mental side of climbing has been studied [3], especially the influence of danger and risk in climbing [7]. There has been less research on using technology in climbing and especially on HCI in climbing. However, there are emerging technologies such as Climbax [5], which provides climbing statistics by utilizing sensors embedded in a wristband.

Climbing consists of motion and performance highly different from everyday activities. Even though climbing strategies and climber movements has been studied, these unique movements and mechanics are currently poorly understood [12]. One main characteristic of full-body movement is the center of mass (COM). There have been only a few studies about tracking the full-body movement of climbers and their COM [13] [17]. These studies have provided first insights on how control of COM affects climbing. Our goal is to have a markerless tracking system for analyzing body movement (e.g. COM) and provide augmented feedback (AFB) during and after the climb.

Augmented feedback, in this case extra information that is provided by a computer system, can be used to enhance sports training. The role of augmented feedback in motor learning and performance has been studied extensively, and when designed properly, AFB can both motivate and guide motor learning [8, 16] [14]. Computer generated feedback can be faster and more accurate than training with a video camera or even receiving feedback from an instructor. It allows a student to do more repetitions and evaluations of a skill in a shorter time. According to Sigrist et al. [14], concurrent visual feedback can especially benefit the initial learning of complex skills. However, it should be kept in mind that the learner may develop a dependency on AFB, as explained by the guidance hypothesis [8].

There are interactive climbing walls, but the research and existing commercial systems have concentrated on attaching sensors and lights to climbing holds [4, 6]. While this approach has it's use cases, our projector and camera setup has many benefits 1) full-body motion tracking for movement analysis and interaction, 2) real-time feedback and interaction with projected


**Figure 3** Top: Creating route while climbing. Bottom: Climbing a loaded route.

graphics, 3) projection on the entire wall to visualize movement trajectories or highlighting holds, 4) configurable system for any climbing wall, and 5) recording the climb for instant replay that is projected to the wall or shown on separate display.

Bouldering can be performed individually, but routes (a.k.a problems) are often "solved" socially with others. The mixed reality mobile application BouldAR by Daiber et al. [1] emphasized the sharing, collaborative training and other social features by providing a way to create, share and define goals and challenges together with friends. Daibler et al. did a promising initial study comparing paper and smartphone based route creation, but they underline that collaborative training needs to be explored more in detail. Our system enables collaborative training. The audience can actively participate, e.g., by defining goals for the climber with a mouse or a touchscreen.

The climbing routes are usually created by skilled climbers and the process takes time. Phillips et al. [11] have developed an assistance system for route setting. For good climbing experience the holds are often color coded for one route and although differently colored routes overlap each other the holds are sparsely placed for easier identification. In some climbing gyms the walls are full of holds and routes are marked, e.g., with pieces of tape, stickers or even not marked at all and verbally passed on. There is a tradeoff between locating the holds belonging to a particular route, and the amount of routes one can have on a wall. With our augmented climbing wall, routes can be easily identified by projected graphics even when the wall is full of holds, thus maximizing a capacity of the wall. Furthermore, anyone can make a route and share it with others who can easily try them even on a different day. Thus the social contact is not restricted to the same time and place, but it can still increase exercise motivation [1, 10].

## Feasibility Study

For initial and technical feasibility study we tested a projector, depth camera and computer setup at a local bouldering gym and tested feasibility of interacting with projected graphics while climbing. Three persons from the research team and a few external climbers participated to the study. Testing involved different types of projected graphics, e.g., 1) animated graphics such as a moving chainsaw or falling objects which a climber needed to avoid (see Figure 2), 2) illuminated static routes, and 3) painting silhouette of a climber to the wall for defining start and end poses.

The main findings were that climbers could observe projected images and interactive graphics while being close to the wall. However, interactive graphics are best located near the holds where the attentional focus of the climber is naturally. Fast moving graphics can be easily missed. Occlusion is not a big problem if projected objects do not appear directly where the climber is. However, the projector has to be powerful for the graphics to be clearly visible in indoor lightning. In our experience, 5000 lumens is enough for an approximately 4x3m projection area.

We found current commercial depth camera data SDKs (*Kinect for Windows* and PrimeSense NiTE) not accurate enough for recognizing individual holds. The skeletal tracking also loses the hands and feet when they are close to the wall. Kinect for Windows v2 Nov 18 2013 technology preview works much better when climber is


**Figure 4** Top: Marking left and right hand positions with a mouse. Bottom: Automatic route generator with 3 changing holds.

close to the wall. However, even the Kinect v2 does not recognize advanced climbing related body poses, as shown in Figure 2, possibly because it is optimized for standing body poses. We are currently working on a custom tracker that reliably recognizes climbing related poses, and hands and feet near the wall.

## Preliminary Wizard of Oz Study

To identify interesting interactions, and to define the requirements for the custom tracking technology, we conducted a Wizard of Oz user study of 6 interaction prototypes. Prototypes were designed by the authors for meaningful climbing related interaction. A researcher carried out some of the tasks that a final software prototype would perform, e.g., detecting the touching of holds or falling and controlling saw animations.

### *Apparatus and Tasks*

To ensure a controlled environment, we built a 3,9m high and 2,5m wide climbing wall in our lab, shown in Figure 3. We used a depth camera (Asus Xtion Pro Live) and a vertically mounted 4800 lumen XGA projector (InFocus IN3124) that was positioned 4,8 meters from the climbing wall. A vertical 24 inch LCD screen was positioned near the wall for video feedback. The prototypes were developed using Unity 3D game engine and a custom plugin that gives Unity access to RGB, depth and skeletal tracking data from OpenNI/NITE and Microsoft Kinect for Windows SDK.

The following prototypes were tested:

- **Projected routes** (Figure 3): Projected routes with illuminated circular holds and connecting lines. Climber can load stored routes and switch between them.
- **Route building** (Figure 3): New route can be defined by climbing. All holds which climber's hands or feet touches are included to a route. Route can be stored for later use. This was implemented so that the experimenter marks the used holds.
- **Delayed video feedback**: After climbing a route a climber can immediately see a replay on a screen. The video replay is automatically triggered, if the system detects falling.
- **Hand marks** (Figure 4): A person waiting for a turn uses left and right mouse buttons to continuously define targets for the climber's left and right hand.
- **Route automator** (Figure 4): Endlessly progressing route for endurance training. The system reveals a next handhold, when previous hold is reached. Statistics show time on the wall and moves made. The experimenter triggered the next hold, which was chosen randomly from nearby holds.
- **Animated Saw**: Climbers avoid animated chainsaws that chase them using predefined routes. This was similar to the feasibility study illustrated in Figure 2.

### *Participants, Procedure and Results*

Eight intermediate and experienced climbers participated the study (female: 1, age: M= 29,9 years SD= 4,6, Max climbing grade: 2x6b, 4x7a, 1x7b, 1x8a French system). Participants performed the experiment in pairs for testing collaborative prototypes and to inspire more discussion. Each test session took about 60 minutes. Participants were asked to try the prototypes and compare them to their regular climbing training. The experimenter administered a structured interview designed for obtaining positive and negative aspects of each prototype.

***Route automator:***

*"100 times more interesting than Climbstation. I would buy this." 8a climber*

*"Good training for unexpected moves" 7a climber*

*"Feels like climbing head in a sack. Not very elegant climbing" 7b climber*

*"Hard" 6b Climber*

***Hand marks:***

*"Interaction with others make this fun" 6b climber*

*"Makes you concentrate on climber's performance" 7a climber*

***Video feedback:***

*"Helps to improve your technique" several climbers*

*"Showing side by side videos of others climbing would be great" several climbers*

*"I have never seen my self climbing" several climbers*

Overall, the augmented climbing wall received positive comments from the participants. All said that they would use the augmented climbing wall, but it would be best as one separate wall in a climbing gym. Easy route building, sharing and instant video feedback were considered the most useful. The social aspect of sharing routes and the possibility to use video screen for comparing own performance to others received praises. Automatic route generator for training was also ranked high. The participants liked its ability to generate unexpected moves and would have liked to use its statistics for tracking personal improvement or competition against other climbers. The animated saw was considered to move the focus away from climbing training and to be more useful for children or in one-time events.

Occlusion of the projected holds by the climber's shadow was seen as the biggest but still a minor problem. The problem was worst for feet, and the occlusion of handholds is typically a problem only when climbing sideways or downwards. We can also think of different strategies for avoiding occlusions: 1) multiple projectors, 2) automatically detecting occluded areas and drawing indicators reaching outside the occluded area, and 3) using projected graphics only for hands and dedicating some holds only for feet.

Most of the participants requested sound effects for directing attention to changing graphics or warning sound especially when a saw is closing in. Sound was also requested for guiding the body movement.

## Discussion and Future Work

Climbing is a good example case of activity where giving real-time feedback is challenging because climber is high on a wall, visual focus is on the holds, and uncommon body positions prevent real-time visual feedback on a screen. We aim to study how to give meaningful AFB during climbing (and other challenging activities) visually or aurally, including, e.g., 1) COM movement and arm trajectories, 2) projections that follow the natural focus of attention, 3) training of specific climbing moves, and 4) quality of movement.

One important aspect is social interaction, which was also pointed out in the user study. Technology can be used, e.g., in sharing routes and high scores for increasing training motivation. It's also possible to provide performance statistics for competing with others and for following individual improvement over time. It should also be studied how to give meaningful information for the audience, enable the audience to interact with the climber, and keep other climbers entertained while waiting.

Based on our study, the main requirements for the tracking technology are 1) detecting what body parts touch the holds, 2) detecting when the climber occludes relevant projected graphics, 3) tracking COM (e.g., for detecting falling), 4) robust skeletal tracking of climbing moves for detailed analysis and feedback, although many interactions can be implemented only using features 1-3. We aim to develop such a tracker for longitudinal studies at a bouldering gym, where the system should work without any setting up by the climbers.

## Acknowledgements

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***Route building:***

*"Social aspect is good." "Easy to create and share the routes" several climbers*

*"Makes possible to have a lot of routes in a small wall" 7a climber*

*" I would use this. Nice idea" 8a climber*

***Animated saw:***

*"Fun. At first at least" 7a climber*

*"Not climbing anymore. Rushing from a big hold to another and keeping eye on the saw" 7a climber*

*"Have to concentrate a lot on the saw, especially when it's close to feet" several climbers*

*"More sounds, effects and blood!" 8a climber*

*"More game-like", "Game feeling makes it fun" several climbers*

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