betaCube – Enhancing Training for Climbing by a Self-Calibrating Camera-Projection Unit

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Abstract
In rock climbing, discussing climbing techniques with others to master a specific route and getting practical advice from more experienced climbers is an inherent part of the culture and tradition of the sport. Spatial information, such as the position of holds, as well as learning complex body postures plays a major role in this process. A typical problem that occurs during advising is an alignment effect when trying to picture orientation-specific knowledge, e.g. explaining how to perform a certain self-climbed move to others. We propose *betaCube*, a self-calibrating camera-projection unit that features 3D tracking and distortion-free projection. The system enables a life-sized video replay and climbing route creation using augmented reality. We contribute an interface for automatic setup of mobile distortion-free projection, blob detection for climbing holds, as well as an automatic method for extracting planar trackables from artificial climbing walls.

Author Keywords
Climbing; sports technologies; augmented reality; collaboration; wearable computing; projection.

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H.5.1 [Information Interfaces and Presentation (e.g. HCI)]: Multimedia Information Systems

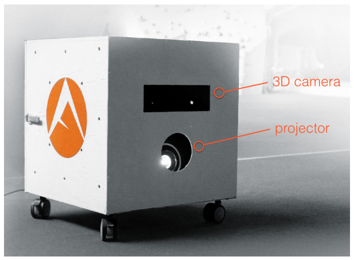

Figure 1: The system consists of a Kinect V2 camera for input and a short-throw projector as output.

Introduction

Climbing, as it is being practiced today, is a complex activity that is determined by a variety of physiological and anthropometric factors. Mermier et al. [6] found that the variance in climbing performance can be mainly explained by a set of trainable variables and less by specific anthropometric characteristics. Climbing, especially during training, is often performed on artificial climbing walls with predefined routes. A climbing route consists of a certain set of holds (often denoted by color). Only these holds are allowed to grab on and - most of the times - a climber needs several tries or even sessions to learn how to perform all the movements of a route successfully.

In the last years, climbing became more and more popular. In the US, 353 climbing and bouldering gyms exist, including 29 newly built gyms (2014) [2]. Even though indoor climbing on artificial walls and plastic was initially thought as a form of training for climbing outdoors, many people only engage in this form of climbing, since it is easily accessible and does not depend on weather conditions. Climbing competitions are solely carried out on artificial walls and thus professional and semi-professional competition climbers mainly train on ”plastic“. Training for climbing has improved from self-coached training in the past to a professionally coached competition sport that is based on a growing body of training literature.

From the perspective of the climbers, climbing is a social activity. Discussing possible solutions with others and getting practical advice from more experienced climbers is an inherent part of the culture and tradition of the sport. A specific route is also called a *problem*. Climbers try to mentally visualize the ascent before climbing, then making an attempt, and finally putting learned movements together. In the climbing jargon, the term *beta* is a synonym for externally given information that is helpful for successfully accomplishing a route. Common beta include the direction to shift the body weight or how to grab a certain hold.

We propose *betaCube*, a self-calibrating camera-projection unit to assist collaborative training for climbing. The system enables a life-sized video replay and climbing route creation using augmented reality. We contribute an interface for automatic setup of mobile and distortion-free projection, blob detection for climbing holds, as well as an automatic method for extracting planar trackables from artificial bouldering walls.

Related Work

Using technology in sports training is nowadays a general practice for analyzing, documenting, and measuring performance and progress, not only in a professional environment, but also for beginners. Examples for that are running watches, which enable the athlete to get real time feedback of her heart rate, distance run, and pace. Additionally, some watches allow to run against a shadow of the wearer, by displaying the lead, compared to a run the user previously did.

Although sports climbing is a relatively new field in HCI, some work exists that addresses training assistance [1, 3], performance analysis [5], and documentation [4].

Daiber et al. [1] investigated handheld augmented reality for collaborative boulder training. They present a mobile augmented reality application to define, document and share boulder problems. Kajastila and Hämäläinen [3] also explored augmented reality for climbing walls by directly augmenting the wall with a projector, using a fixed setup. A preliminary Wizard-of-Oz study with six interaction prototypes and structured interviews showed that users liked the system. Our system differs by its ad-hoc deployment

Figure 2: A successful ascent is stored in the user's climbing history and a notification is pushed to her wearable.

Figure 3: Screenshot of the route selection interface. A simple flick with a finger changes the currently projected route.

and ease of use. To the best of our knowledge, *betaCube* is the first system that can be placed in front of an arbitrary shaped bouldering wall and setup by even novice users. Former systems were either concepts only or based on a fixed supervised setup and could only project on flat walls.

With ClimbAx, Ladha et al. [5] presented a system for climbing performance analysis, that used wrist-worn accelerometer sensors to assess power, control, stability, and speed of the climber. An evaluation of the system during a climbing competition resulted in a positive correlation between the predicted and the actual score of the participants.

Kosmalla et al. [4] introduced ClimbSense, a system to record and automatically recognize successfully climbed routes. In their approach the climber is equipped with wrist-worn Inertia Measurement Units (IMUs). With the help of the IMUs, a corpus of climbing data was collected to train a classifier that is able to recognize different routes.

Design

When designing the *betaCube*, our goal was to build a system that is easy to setup, intuitive to use, and enhancing training for climbing rather than changing the way climbing is practiced: it can be used like a smartboard to find, explain and solve climbing problems in a collaborative manner. This is achieved by using a combination of a 3D camera and a projector, supplemented by an augmented reality smartphone application.

To setup the system, the climber moves the *betaCube* in front of the desired climbing wall and connects it to a power source. By pressing the calibration button, the automatic setup process is initiated, after which the *betaCube* is ready to use. This calibration process even works on uneven surfaces and volumes of every shape. The fact that the system is consolidated in a cube with an edge length of 23" (59cm) makes it very flexible and eliminates the need for any other instrumentation of the climbing gym or complicated installations.

Figure 4: Setup of the system. The *betaCube* can be placed in front of an arbitrary climbing wall. Holds are highlighted by a projector.

BetaCube offers a variety of possible applications. Right now we implemented route creation and browsing, climb recognition, and video functions. The *betaCube* is controlled either via the buttons on the cube itself or an accompanying smartphone app. To create a route, the augmented reality function of the app is used; by looking through the camera image of the phone and touching the desired hold, the system recognizes the hold on the wall and projects a marker around it, creating a visual representation of a new climbing route (see Figure 4). The route can be stored and already existing routes can be browsed with a swipe of a finger (see Figure 3). When climbing a predefined route, the system recognizes a successful ascent and stores it in the climber's personal history while pushing a notification to her wearable (see Figure 2).

Furthermore, the system allows for video recording and playback. A long press on the video button of the box (or a tap within the application) starts the recording. The playback can be controlled by both the app or a short press on the video button. Recordings can be used by the climber to observe her previous ascend, or the ascend of another climber. When using the recording of a second climber, the exact movements of this climber can be imitated by climbing in parallel of the recording.

Implementation

The *betaCube* is a wooden cube with an edge length of 23" (59cm). It contains a projector, a Kinect V2 camera, a laptop computer, a WiFi router for the communication with the smartphone app, and an Arduino Fio to interface the physical buttons of the cube.

Setup

The calibration and projection mapping is based on the Microsoft RoomAlive toolkit[1]. We integrated the calibration process, so that a simple click on the physical setup button of the *betaCube* starts the calibration process: a pattern of horizontal and vertical patterns is projected on the climbing wall, ensuring a distortion-free projection on planar and uneven surfaces, as also on any kind of volumes mounted on the climbing wall. This one-click calibration process enables even novices to setup the *betaCube* in front of an arbitrary climbing wall within minutes. The system is currently restricted to bouldering walls of approximately 4.5×3 meters without affecting the tracking quality of the Kinect. However, the usable area can be extended by deploying multiple cubes.

Figure 5: Using perspective projection and blob detection, the selected hold is highlighted.

[1] https://github.com/Kinect/RoomAliveToolkit

Route Creation

An accompanying Android app is used as both, a remote control and an input device for the *betaCube*. For this, the smartphone connects with the cube using the built-in WiFi router. To create a new route, the user selects the route-creation mode and is presented with the camera image of the back-facing camera of her smartphone. When pointing the phone to the wall and touching a hold in the camera image, the image gets transferred to the cube, where it is processed.

To highlight the respective physical hold on the climbing wall, a combination of feature matching, homography finding, and visual hold detection is used. During the setup, phase an image section of the Kinect color image is determined that serves as trackable. Using the depth stream of the camera, a planar surface of the climbing wall is identified, that is later on used as trackable for the image recognition.

Whenever the user touches a hold on the camera image, the image as well as the coordinate of the touch on the camera image is transferred to the server inside the *betaCube*. The server software determines the image features in the received phone image and tries to match these with the trackable found during the setup phase. The resulting perspective projection is used to translate the coordinate of the touch on the phone image to a coordinate in the camera image. With this technique no additional artificial markers are needed.

Due to inaccuracies of the perspective projection and the fat finger problem, the selected point on the smartphone is not fully consistent with the Kinect color image of the climbing wall. This results in highlights of the individual climbing holds which are slightly off. To overcome this issue, a blob detection is performed during the setup phase of the *be-*

taCube. The result of the blob detection algorithm are the coordinates of the individual climbing holds. In a final step, the coordinate obtained by the perspective projection is snapped to the nearest coordinate of a climbing hold. This results in a highlight which is nicely centered around the desired climbing hold (see Figure 5).

Climb Detection
When climbing a created route such as described above, the system can recognize a successful ascent of the climber using the skeleton tracking of the Kinect camera. Although the skeleton tracking is not very robust during climbing due to occlusion and ”unnatural“ body postures (see also [3]), the center of mass of the skeleton is sufficiently accurate for detecting if the climber reached the top of the climbing route. In this case, the attempt is stored as a success in the user's climbing history including the elapsed time and effort. The latter is obtained from a Microsoft Band 2, which features a heart rate, a galvanic skin response, and a skin temperature sensor. As confirmation, a notification is pushed to the smart band.

Video Recording and Playback
For video recording and playback, the color stream of the Kinect is used. By pressing the video button on the *betaCube* or using the smartphone app, the recording is started. To replay the latest recording, the video button is pressed. Using the smartphone application, a list of already existing recordings can be browsed and the usual video controls like backward, forward, play and pause are available. With the projection matrix obtained using the RoomAlive toolkit, the video is projected on the exact same position of the recorded climber, resulting in the opportunity for interesting interaction types.

Figure 6: Physiotherapeutic exercise for strengthening the back musculature that could be recorded and replayed using *betaCube*.

Types of Interaction
At the time of submission, we have implemented a first set of interactions with *betaCube*, although more are planned and will be explored as well as evaluated in future user studies. We were first focused on the interactive creation of routes and on interactions based on recording and replaying distortion-free and spatially correct aligned videos.

Life-sized Video Analysis
By using the app or a button on the box, the system can record an attempt of the climber or another person and play the video using the projector following the movements of the climber on the wall afterwards. This feature can be used to explain difficult parts of a route by using the video as supportive material. Our approach has the following advantages over traditional video analyses: Firstly, the trainer requires a different viewing position for analysis as the climber. *BetaCube* provides both at the same time because one freely roam around the projected climber. Secondly, the alignment effect when viewing the video on a screen can be avoided. For example, the position of a specific hold from the video can be easier aligned with the real world when using the life-sized projection.

The advantage is that individual movements can be explained and demonstrated by someone else while not having to climb simultaneously. Another person can directly see in place the specific steps and holds that were used.

Shadow Climbing
This feature can be leveraged for *shadow climbing*. Shadow climbing is a type of interaction, in which a climber directly follows an attempt by imitating the movements of the recorded climb. It can be used to precisely copy the body posture of another climber, which helps to understand a specific hard move, and thus enables the climber to master the ascent. Another option is to climb against the shadow,

i.e. climbing faster or more efficient as another climber or herself.

Opportunities with betaCube

The system *betaCube* is not only restricted to the field of sports climbing. In the following section, we discuss other versatile application scenarios in which the flexibility of the system could be advantageous.

Health Care

In living environments, *betaCube* could be used for physiotherapeutic treatment and might temporarily be lend by a health insurance. If a professional therapist prescribes certain exercises that can also include mechanical devices, the system can be used to track the progress, i.e., the number of repetitions. Moreover, it would prevent injuries and strengthen specific muscles of the patient by assisting her to perform a certain exercise as accurately as possible (see Figure 6 for an example). Even more complex sequences of exercises can easily be programmed by a trained professional using the recording feature of *betaCube*. The advantage would be that the patient could replay the professional advice as many times as she wants, if necessary.

People who do not suffer from injuries could also benefit from the system at home. One example is yoga, which is a very popular sport. However, yoga exercises can also be dangerous if incorrectly performed. Similar to the speech guidance in [7], assistance could be given using the projection feature of *betaCube*. By tracking the body position while replaying an exercise it is possible to advise precise timings, as required by personal training goals.

Telepresence

In the field of climbing, we can think of telepresence as a powerful interaction method when climbing together remotely. Therefore, a wall must be setup equally with the same type of climbing holds. In such a way, a route that was created using AR on one site could be shared to another site digitally. Furthermore, a climber on one site *A* could be projected in real-time to another site *B* while someone else is climbing on the similar route. That way climbers could interact and share information with each other remotely. For climbing competitions, which are currently limited in the number of participants due to their spaciousness, telepresence would enable a way to connect multiple climbing facilities. In such a way, climbers could compete amongst each others at different locations and had a way to validate and present a remotely recorded attempt.

Conclusions and Future Work

We presented *betaCube*, a self-calibrating camera-projection unit for collaborative training for climbing on artificial bouldering walls. While building and testing our system in a climbing gym we had many informal discussions with route setters and climbers. This initial feedback was very promising and directly informed the design of the current prototype. As our work is still a work in progress, we would like to discuss future user study designs and promising interactions to implement at CHI. In the future we would like to explore more interaction techniques as well as games. Furthermore, we plan an into-the-wild study by leaving the *betaCube* in a climbing gym without supervision, recording all usage data.

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