Juggling 4.0: Learning Complex Motor Skills with Augmented Reality Through the Example of Juggling

Benjamin Meyer
OFFIS - Institute for Information Technology
Oldenburg, Germany
benjamin.meyer@offis.de

Pascal Gruppe
University of Oldenburg
Oldenburg, Germany
pascal.gruppe@uol.de

Bastian Cornelsen
University of Oldenburg
Oldenburg, Germany
bastian.cornelsen@uol.de

Tim Claudius Stratmann
University of Oldenburg
Oldenburg, Germany
tim.claudius.stratmann@uol.de

Uwe Gruenefeld
University of Oldenburg
Oldenburg, Germany
uwe.gruenefeld@uol.de

Susanne Boll
University of Oldenburg
Oldenburg, Germany
susanne.boll@uol.de

ABSTRACT
Learning new motor skills is a problem that people are constantly confronted with (e.g. to learn a new kind of sport). In our work, we investigate to which extent the learning process of a motor sequence can be optimized with the help of Augmented Reality as a technical assistant. Therefore, we propose an approach that divides the problem into three tasks: (1) the tracking of the necessary movements, (2) the creation of a model that calculates possible deviations and (3) the implementation of a visual feedback system. To evaluate our approach, we implemented the idea by using infra-red depth sensors and an Augmented Reality head-mounted device (HoloLens). Our results show that the system can give an efficient assistance for the correct height of a throw with one ball. Furthermore, it provides a basis for the support of a complete juggling sequence.

Author Keywords
Augmented Reality; Tracking; Physical Model; Interaction; Motor Skills; Juggling

INTRODUCTION
Recent advances in technology offer the chance to interact with our surroundings in an unprecedented way. However, our way to learn still follows the same methods that were introduced and established centuries ago. In contrast, Science-Fiction suggests novel approaches (e.g. by directly uploading a skill to the human brain, as shown in the film Matrix). With the rise of Augmented and Virtual Reality (AR and VR) devices as well as their ability to create artificial or extended worlds, we can investigate a new way of gaining and transferring knowledge. As related papers show, VR techniques can effectively be used for educational purposes: they can help patients relearn and rehabilitate certain motor skills during therapy [2, 4]. Moreover VR can even be used to support the learning process of new motor skills such as juggling [3]. Additionally people can be trained in VR to learn skills that are cumbersome to acquire in a real life scenario [1]. These promising features represent a significant evolutionary step on how individuals can learn complex motion sequences.

In our work we propose a solution to improve the method of learning by using AR to also incorporate real-life objects as opposed to the pure virtual approach stated before.

CONCEPT
The challenge that comes with the idea behind this work is to support the user with real time feedback to better learn a complex motor skill. We chose juggling as a representative skill as the movement is not known by many people and is not too complex to learn. To effectively give feedback for this motor skill we perform three actions:

1. Capture the status quo, which is the actual movement of the user as well as the positions of the balls involved.
2. Use the gathered data to calculate the trajectories of each ball as well as the distances they will travel in all three dimensions.
3. Give adequate visual feedback based on the calculations that were made beforehand.

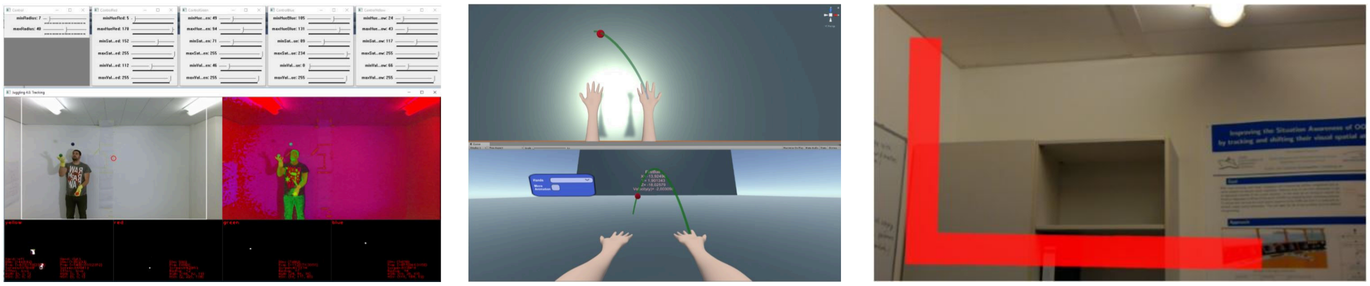
To manage the in- and output of each subsystem we also need to develop a main program that handles the order of each processing step.

PART I: TRACKING
The used balls and the hands of the person are tracked in three dimensions and in real time. For supporting a complete training session it is also essential to recognize and identify these objects throughout the whole process. This is achieved

UIST '18 Adjunct October 14–17, 2018, Berlin, Germany

ACM ISBN 978-1-4503-5949-8/18/10.

DOI: https://doi.org/10.1145/3266037.3266099



(a) Tracking (b) 3D Model (c) AR-Interaction

Figure 1: The three sub-components of our approach

by using a Microsoft Kinect V2 in combination with OpenCV[1] based image processing algorithms, which are implemented in C++. As all objects are distinguishable by their colour (red, green, blue for the balls; yellow gloves for the hands), they can be identified using thresholding techniques. To further grasp the form of the objects and allocate their positions, we use the contour finding algorithms that are based on the work of Suzuki [6] and Sklansky [5]. This procedure results in the data that is necessary for the further calculation: the position and timestamp for each object.

PART II: 3D MODEL

The generated data from the tracking subsystem is fed into a model of the juggling process. This model consists of three dimensional representations of the tracked objects. These were designed in the 3D animation software Blender[2] and incorporated in Unity[3]. To ensure a physically realistic behaviour of the balls, the principals of the oblique throw were adapted:

1. $x = v_x t + x_0$ for the distance travelled in the horizontal directions (x and z)
2. $y_{max} = v_y t - \frac{g}{2}t^2 + y_0$ for the maximum height of a ball, where t is equal to $\frac{v_y}{g}$ which represents the time to reach the highest point

These were then unified in the following vector form:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0 \\ -\frac{g}{2} \\ 0 \end{pmatrix} t^2 + \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix}$$

The calculations are encapsulated in an independent package that can be used separately in the main program. This way we can refrain from displaying the 3D models in a live setting to increase performance.

PART III: AR INTERACTION

To make use of the generated data from the model we first need to perform a calibration process that maps the three-dimensional data from the Kinect to the data from the HoloLens. Otherwise we are not able to give feedback that is relative to the viewing angle of the user. This is done by manually placing a virtual object of the Kinect to its real counterpart with the help of speech commands that are recognized by the HoloLens. Once the object is placed correctly, the viewing angle of the Kinect can be considered in the virtual environment of the HoloLens. Afterwards, the initial hand positions ar locked as a reference point for the ideal height. One critical part of the AR assistant is to give feedback in real time. As this was the first implementation attempt, we limited ourselves to only use visual feedback. This kind of assistance is easy to implement and is the most common one in the field of human-computer interaction. The hints are displayed in the form of red bars. These are projected into the field of view of the participant and indicate that the ball went too far in the displayed direction.

EVALUATION

We follow an empirical approach involving study participants to evaluate the implemented system on the basis of their insights and feedback. Each participant performs a previously defined procedure before depicting their subjective experiences in an interview. The procedure includes the before mentioned calibration and throwing one red ball 100 times into the air. Purpose of this early stage evaluation is to assess whether the system can efficiently provide support to reach a previously defined ideal height. This target figure can be seen as one part of an ideal juggling movement.

Participants

There were 6 participants involved from age 19 to 37 (mean: 24.5, SD: 5.94), where all of them had normal or corrected to normal eyesight. One of the participants had experience with using an AR device.

Results

Results of the experiment show that the majority of the participants find that the given visual support was helpful to reach a specific height region consistently. However, most of the participants needed some time to distinguish between a *too high* and a *too low* hint as was no reference point in the middle of the displayed area. Also the weight and general design of the HoloLens was perceived as unhandy. In addition the range of tolerance for reaching the specified height was too low according to the participants. Hence, it was quite difficult to reach the accepted region although a feedback was given. All in all the results of the conducted interviews show that

[1] https://opencv.org/, last retrieved: August 16, 2018
[2] https://www.blender.org/, last retrieved: August 16, 2018
[3] https://unity3d.com/de, last retrieved: August 16, 2018

our approach is supportive for one target figure of juggling: reaching a predefined ideal height.

Discussion

Based on the positive outcome of the evaluation the implemented system can be extended to support other necessary attributes of the juggling process, such as an ideal width for each throw or the correct timing. Furthermore, it is imaginable to transfer this general approach to other complex motor skills as well.

CONCLUSION

In our work we propose an approach to improve the learning of complex motor skills with AR through the example of juggling. The effective and efficient use of the given, state of the art hardware as well as the communication between the sub-systems was critical to implementing this idea. Results of the early stage evaluation show that users can repeatedly reach a specified, ideal height-range which is one important part of learning how to juggle. Furthermore, the implementation of this work represents a blueprint of how to create an Augmented Reality assistant for learning new motor skills.

REFERENCES

1. Randy S Haluck and Thomas M Krummel. 2000. Computers and virtual reality for surgical education in the 21st century. *Archives of surgery* 135, 7 (2000), 786–792.
2. Amy Henderson, Nicol Korner-Bitensky, and Mindy Levin. 2007. Virtual Reality in Stroke Rehabilitation: A Systematic Review of its Effectiveness for Upper Limb Motor Recovery. *Topics in Stroke Rehabilitation* 14, 2 (2007), 52–61. DOI: http://dx.doi.org/10.1310/tsr1402-52 PMID: 17517575.
3. Rotem Lammfromm and Daniel Gopher. 2011. Transfer of Skill from a Virtual Reality Trainer to Real Juggling. *BIO Web of Conferences* 1 (2011), 00054. DOI: http://dx.doi.org/10.1051/bioconf/20110100054
4. Mindy F Levin, Patrice L Weiss, and Emily A Keshner. 2015. Emergence of virtual reality as a tool for upper limb rehabilitation: incorporation of motor control and motor learning principles. *Physical therapy* 95, 3 (2015), 415–425.
5. Jack Sklansky. 1982. Finding the convex hull of a simple polygon. *Pattern Recognition Letters* 1, 2 (1982), 79–83.
6. Satoshi Suzuki and others. 1985. Topological structural analysis of digitized binary images by border following. *Computer vision, graphics, and image processing* 30, 1 (1985), 32–46.