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Summary
of the Ph.D. thesis entitled

Range imaging based obstacle detection for virtual environment systems and interactive metaphor based signalization

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by
Peter Wozniak

Supervisor : Nicolas Javahiraly (MCU-HdR). University of Strasbourg, ICube
Co-Supervisor : Dan Curticapean (Professor) University of Applied Science Offenburg
Thesis adjunct adviser: Antonio Capobianco (MCUHdR) ICube

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Summary of thesis

Virtual Reality (VR) is currently experiencing a time of prosperity. Already in the 90s various manufacturers tried to make the technology mass-ready. Unfortunately the equipment at that time could not meet the high expectations of the audience and so VR was not successful in the mass market. The state of the art at that time had too many limitations. The high weight of the helmets, a very small field of view and too slow computers have made the few products on the market fail. The biggest problems were the pricing of the equipment and the occurrence of simulator sickness among many users. Nevertheless, the technology has been further developed and has been applied in industrial and scientific research facilities. A resurgence of broad public interest in the VR was not seen until the early 2010s. The technical advancements made it possible for manufacturers like Oculus and HTC to make the necessary hardware components for VR simpler, cheaper and yet more powerful. With this generation of devices, VR has actually made it into the living rooms of end-users. These devices feature 6-DOF tracking, allowing them to move naturally in virtual worlds and experience them even more immersively.

But for a natural locomotion in the virtual, one needs a corresponding free space in the real environment. The available space is often limited, especially in everyday environments and under normal spatial conditions. Furnishings and objects of daily life can quickly become obstacles for VR users if they are not cleared away. Since the idea behind VR is to place users into a virtual world and to hide the real world as much as possible, invisible objects represent potential obstacles.

The currently available systems offer only rudimentary assistance for this problem. If a user threatens to leave the space previously defined for use, a visual boundary is displayed to allow orientation within the space. These visual metaphors are intended to prevent users from leaving the safe area. However, there is no detection of potentially dangerous objects within this part of space. Objects that have not been cleared away or that have been added in the meantime may still become obstacles.

This thesis shows how possible obstacles in the environment can be detected automatically and how users can be effectively warned about them in the Virtual Environment (VE) without significantly disturbing their sense of presence. In addition to the input and output modalities important for VR systems and the associated input and output devices, depth perception systems are presented. These represent an important component for the realization of obstacle detection. With depth perception, the geometry of the environment can be recorded by distance measurements and mapped as a depth map. Depth maps combine a projective image and a depth measurement of the environment in the form of a 2D data matrix. The methods differ in the physical principles used, but are classified under the term range imaging due to the data generated. Depth maps can be easily visualized and interpreted as a 3D point cloud. Depth Maps make it possible to draw conclusions about the room geometry and
the objects in the space. This makes them ideal for determining obstacles - and in particular their position and dimensions - in space. This special form of tracking can be solved particularly well with camera-based range imaging methods. These allow entire sections of space to be captured at high frame rates, and are sufficiently robust and easy to use in everyday situations.

Similar to the well-known paradigms for desktop or mobile applications, on which numerous user interfaces are based, it is also necessary to develop paradigms for VR applications that are adapted to this form of human-computer interaction. There are several existing techniques to detect parts of the physical environment (PE) and its properties and to use this information for interaction with and within the virtual world. But none of these systems combines automatic obstacle detection and its signalling using metaphors.

For the implementation of our VE system we used the game development environment Unity\(^1\) and SteamVR\(^2\) (HTC Vive). Microsoft’s Kinect\(^3\) 2 time-of-flight (ToF) camera sensor was used for depth perception of the scene. The acquisition, processing and visualization of the depth map data was limited by the execution as Unity program code and was thus complemented by a C++ implementation, which allows a more effective and faster execution. A realization as a natively executed C++ program library also offers the advantage of using the PCL\(^4\) function library, which provides a wide range of functionality especially for working with point cloud data.

The developed system is able to display the information of the range imaging sensor in real time as a point cloud in the VE. By performing a calibration process it is possible to determine the exact pose of the depth imaging sensor and to represent the point cloud in the virtual world analogous to the real world. Similar to an image registration, a three-dimensional registration of the PE and the depth map information in the form of a point cloud allows to map the information from the measuring space of the range imaging sensor into the measuring space of the VE-tracking system with pinpoint accuracy. Obstacles in the PE can be identified using the depth map information and signalled precisely within the VE. First, the largest detectable plane within the point cloud is determined and suitable bounding boxes are calculated for the point clusters located on top of it. The recognition was realized with the help of the PCL function library. Different possibilities of the optimization of the execution speeds, which are critical for VE applications, are demonstrated. The focus was to avoid disturbing delays and interruptions of the image generation and to minimize possible simulator sickness.

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\(^1\) **Unity** is a 3D game engine - [https://unity.com/](https://unity.com/)

\(^2\) **SteamVR** is the name of VR hardware also known as HTC Vive - [https://store.steampowered.com/steamvr](https://store.steampowered.com/steamvr)

\(^3\) **Kinect** is the name of a range imaging sensor - [https://developer.microsoft.com/en-us/windows/kinect](https://developer.microsoft.com/en-us/windows/kinect)

\(^4\) **Point Cloud Library** is a C++ based function library for point cloud processing - [http://www.pointclouds.org/](http://www.pointclouds.org/)
With the exception of the acquisition and processing of the Kinect depth image information, which was realized in C++, the VE system was developed using the Unity game engine. Four interactive visual metaphors are used to signalize the obstacles within the VE. The first metaphor represents a well visible placeholder object at the position of an obstacle. An arrow similar to the principle of the compass needle, pointing to the next obstacle, served as the second metaphor. The third and fourth metaphor consisted of a ring-shaped band floating around the virtual centre of the user's body. They differ in their interaction with the obstacles in the PE. The third metaphor is constantly visible to the user and is deformed and dented by virtual contact with an obstacle like an elastic rubber band. The position of the deformation and its intensity indicates the position and size of the obstacle in space. The fourth metaphor only becomes visible when an obstacle is in the immediate proximity. The remaining distance to the object is represented by a spatially coloured signal.

With the help of a user study, the four signalling variants and the obstacle detection were tested. For this purpose, a simple virtual scene was created in which the participants had the task of picking up a virtual object at one end of the walkable virtual scene and carrying it to another location. Invisible to the test persons, two obstacles were randomly placed in the area. These were automatically recognized by the system and then visually signalled within the VE. The aim was to demonstrate the basic suitability of the chosen approach and to examine the four chosen metaphors with regard to their precision, understanding and influence on the presence when used as an obstacle signalling method in VR applications. The results of the study show that the metaphors tested work well enough to avoid collisions with randomly placed objects in space. However, they clearly differ in the spatial accuracy with which the participants were able to locate the signalled metaphors. Surveys have also shown that there is a clear preference of the test participants for the various methods.

The system developed and tested in the context of this thesis represents a solid basis for the further research of interactive obstacle signalling methods for VE systems. It implements the necessary functionalities and demonstrates them on the basis of the conducted study. Due to the large number of possible VR applications, however, it does not make sense to aim for one method for all eventualities. The necessity to extend the existing system for the detection of moving objects seems clear. In addition, the extension by further depth sensors, which detect an as large as possible section of space from several directions, could help to avoid problematic cases of obscuring the detection area and to make the recognition of obstacles more reliable and robust. Furthermore, the system can be relatively easily extended by adding various metaphors for signalling obstacles, enabling them to be tested and compared.
Scientific communication

2019
Accepted International Conferences


2018
International Conferences


2017
International Conferences


2016
International Conferences

[7] Wozniak, Peter; Vauderwange, Oliver; Javahiraly, Nicolas; Curticapean, Dan. Possible applications of the LEAP Motion controller for more interactive simulated experiments in Augmented or Virtual Reality. SPIE Optics + Photonics 2016, Optical Engineering + Applications, Optics Education and Outreach IV, San Diego, USA, (2016).


2015

International Conferences


[12] Vauderwange, Oliver; Haiss, Ulrich; Wozniak, Peter; Israel, Kai; Curticapean, Dan. Active Learning In Optics And Photonics - Liquid Chrystal Display In The Do-it-yourself. 13th International Conference on Education and Training in Optics & Photonics (ETOP 2015), Bordeaux, France, (2015).

2014

International Conferences


2013

Proceedings


Poster sessions

[17] Poster session and presentation about the thesis at University Offenburg in March 2016.

[18] Poster session presenting thesis at University Strasbourg in October 2015.
Doctoral Training (Plan Individuel de Formation)

Seminars and PhD courses:

   - 3D Image Acquisition and Display: Technology, Perception and Applications
   - Computational Optical Sensing and Imaging (COSI)
   - Digital Holography & 3-D Imaging (DH)

2) Communication Skills in Scientific English Seminars and courses in Strasbourg

3) Eco-friendly Fabrication of Organic Solar Cells

4) EBIPREP – Nutzung von Biomasse zur Erzeugung erneuerbarer Energie und biotechnischer Wertstoffe

5) Präzise, modellfreie Kalibrierung von Kameras und Smartglasses für Mixed-Reality Anwendungen in der computerassistierten Chirurgie

6) INES: Das Schäffler Hybridmodul

7) What is the definition of a good machine learning algorithm?

8) Europe - Visite en anglais du Conseil de l'Europe 22.03

9) ESE - Propriété Industrielle (en anglais) : protéger par le brevet (2)

10) IST - Computational Musicology between scientific research and artistic practice

11) IST - Gouvernance de la durabilité dans les villes européennes (en anglais)

12) IST - Finding a needle in a haystack. How optics meets robotics and electronics to improve medical imaging for early diagnosis

Visited Courses:

13) Parallele Programmierung und Algorithmen

14) Mobile Computing

15) Corporate Communication