Toward Cyber-Physical Research Practice based on Mixed Reality

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Abstract

Research practice has benefited greatly from advances in technology. Yet, disciplines handling physical objects still experience several limitations when connecting analog research practices to digital resources. Utilizing recent developments in mixed reality technology, we propose a digital research environment that overcomes these limitations. We present a soft- and hardware prototype that blends analog annotation practices with its digital counterpart. Our approach advances the state of the art by enabling real-time handling of digital representations by manipulating actual physical objects. We discuss our future work concepts of blending objects and augmenting information using mixed reality technologies, and connecting object-centered research practices to online data sources.

1 Introduction

The World Wide Web was designed to allow researchers all over the world to share their research ideas and results based on a simple information-sharing model. Since then, however, the Web has changed fundamentally. Nowadays, it provides an ecosystem of user-contributed content, and it exhibits an increasing amount of structured data that denotes the meaning of existing, user-contributed content. In parallel, research practice has evolved as well. It has become more data-intensive and more focused on digital working practices (Hey et al. 2009). E-research infrastructures have emerged, providing access to digital research data, such as databases or 3D-models. Despite these initiatives, there still is a gap between the digital web-based space and the traditional object-bound physical space. This separation is particularly apparent in research disciplines that revolve around physical objects – such as archeology, medicine, paleontology, or engineering. In these contexts, physical objects

Veröffentlicht durch die Gesellschaft für Informatik e. V. 2017 in
M. Burghardt, R. Wimmer, C. Wolff, C. Womser-Hacker (Hrsg.):
Mensch und Computer 2017 – Workshopband, 10.–13. September 2017, Regensburg.
 https://doi.org/10.18420/muc2017-ws08-0347

anchor the communication and research processes. They gain an active role in the "reflective situation" (Schön 1983).

The question that motivates this research is how to close the gap between physical and digital research processes by designing suitable translation mechanisms between the digital and the physical realm. Our goal is to leverage object-centered research practice by allowing researchers to interact with physical and digital objects seamlessly within a computer-supported research environment by employing mixed reality (MR) technologies.[1]

This research-in-progress aims at making the following contributions:

(1) Present a first prototype for a translation mechanism that connects object-centered research practice to a digital representation. More particularly, the research practice of "object annotation" serves as a paradigmatic model.

(2) Introduce the concept of a computer-supported research environment that extends the existing concept by connecting research data and physical objects by means of MR.

This paper first outlines the conceptual frame and reference work which are related to the approach we follow. It then describes the current functionality and status of the prototype we developed based on this approach. Finally, it presents the concepts and research directions that guide us in our present and future work.

2 Related Work

The presented prototype is conceptually based on (Schön 1983)'s ideas of object-centered collaboration on the one hand, and embodied interaction with computers as described by (Dourish 2001), (Klemmer et al. 2006), or (Weiser 1991) on the other hand. The relevance of their work to ours is that we approach our envisioned system not only from a technical perspective, but also from that of interaction design.

Object-centered annotation processes have been investigated by (Jung et al. 2002). They propose a system that enables users to leave annotation marks on the 3D representation of a building. (Wu et al. 2008) developed a tool to display and create virtual annotations to real-life books by means of projection and camera tracking of gestures. The "ModelCraft" project by (Song et al. 2006) combined physical objects models made of digitally traceable paper with a tracking pen. This allows users to annotate and suggest changes to the model by drawing directly on the surface.

The presented prototype builds upon this state of the art in several aspects. To begin with, in our setup the object of interest is a physical object. This is in contrast to the work of Jung et al., where object representations remain virtual. Moreover, we make use of a full three-

[1] We will use the term "mixed reality" throughout the paper for simplicity. Following Milgram and Kishino, MR encompasses a broad spectrum from augmented to virtual reality (Milgram & Kishino 1994).

dimensional handling of objects. This, in turn, is also contrary to Wu et al.'s 2D plane approach and the ModelCraft system by Song et al. Thus, by combining physical object input, real-time tracking in fulls 3D space, and persistent virtual object editing, we provide a new approach for object-centered interaction.

3 Linking Physical and Digital Object Interaction

To achieve our aim of narrowing the gap between physical and digital research processes, we chose the research practice of "object annotation" as our case study. What makes annotation particularly interesting for this purpose is that it initiates subsequent acts of focusing, information filtering and investigation of details. Our prototype demonstrates a tangible process that synchronizes annotation activities on a physical object with its virtual 3D representation in real-time. The aim is to enable users to interact as naturally as possible with their relevant objects, both in physical and digital form.

Our prototype consists of three components:

(1) Two hardware devices (*Adafruit Feather Bluefruit LE Micro Board)*, each featuring an orientation sensor (*BNO055 9-DOF absolute orientation sensor*) which detects the rotations of a physical object and of the pointing device, respectively. Users initiate an annotation by pressing a button on the pointing device. Both devices are connected to the software via Bluetooth LE.

(2) A graphical software tool which captures annotation activities and displays them on the digital object. The software tool is built as a native application using the *Electron* framework. It utilizes web technologies like *Polymer*, *three.js* and *pouchdb*.

(3) A server backend (*Node.js*) connected to a database (*CouchDB*). It stores the live sessions as well as all object and annotation data, and provides an application programming interface for integrating external data sources.

The interaction with the setup works as follows:

(1) Given a physical object to be annotated, the user first selects or uploads a fitting 3D model of that physical object into the software. The current version of the prototype allows to load CAD files in OBJ and STL format.

(2) The user then attaches one of the bluetooth-enabled devices to the physical object, with the second device working as a pointing device.

(3) To create an annotation, the user holds the physical object in one hand and the pointing device in the other hand. While freely rotating both of them, the user keeps the pointing device constantly directed towards the physical object's center. When it points to a desired part on the physical object's surface, she presses the button on the pointing device. For visual feedback, the virtual representations of the pointing device and of the physical object in the graphical user interface will also reproduce these movements in real-time. The pressing of the button then binds an annotation to the point on the physical object's surface where it

intersects with the pointing device's extended axis while it is oriented towards the physical object's center.

(4) The user then creates the textual content of the annotation by typing it on the computer keyboard, or by a speech-to-text recognition utilizing the *Watson Natural Language Processing API*.

This current setup captures and supports the common research practice by which physical objects are being passed around in a meeting room, while meeting participants point at details and comment on them. Figure 1 shows the prototype in action.

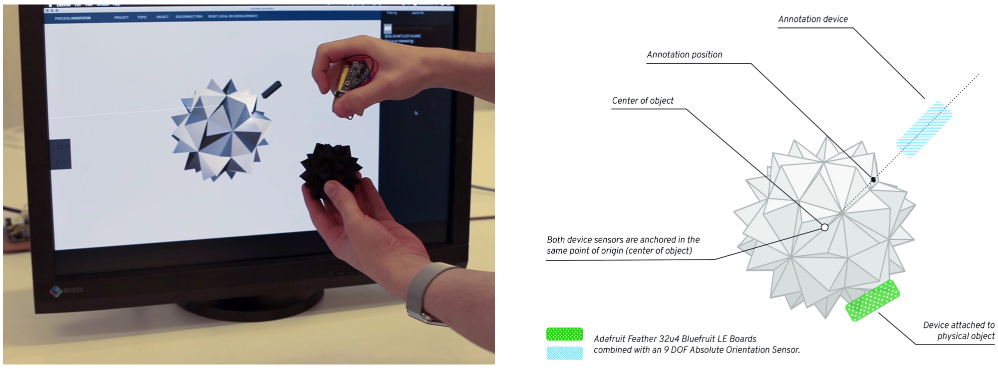

Figure 1 Left: An annotation is made in direct interaction with a polyeder using the pointing device. The software in the background displays a synchronized virtual representation of the polyeder and the pointing device. Figure 1 Right: The involved hardware components and their setup.

4 Future Work

Our vision is a research environment that seamlessly blends between digital and physical objects, and effortlessly interconnects both of them to data sources available online. To achieve this, our research moves in two directions.

In one research direction, we are working on methods to replace the computer screen visualization by mobile solutions – either using readily available smartphones, or MR devices like the Microsoft Hololens. This allows for a process as illustrated in Figure 2, where a physical object is being annotated using our software, and the annotations are made visible and editable again on the very physical object by means of a smartphone display overlay, or as floating MR displays in 3D space.

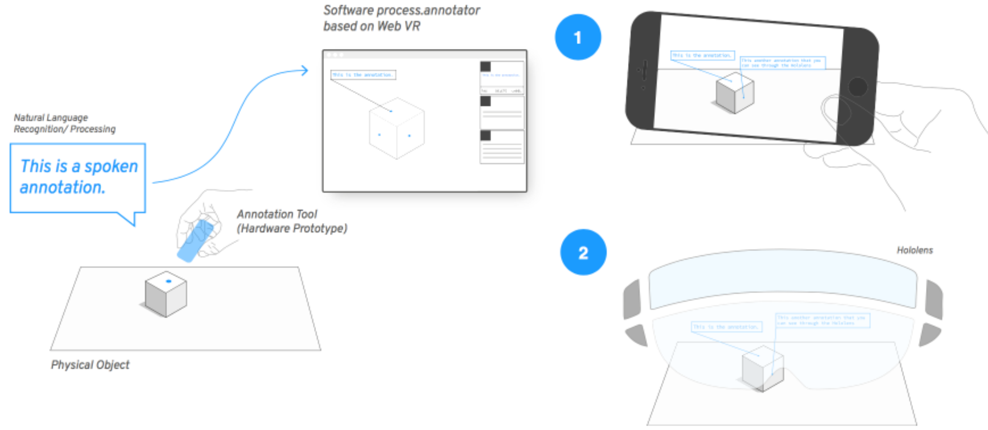

Figure 2: An envisioned environment where annotations can be created on the physical object, stored on the digital representation of it, and made visible again on the physical object.

In the other research direction, we want to increase the value of being able to display annotations by connecting the setup to external sources of research data. An example is the rising number of museums that currently make their collections available online. The strict format of these databases makes them suitable for queries that can yield useful information to connect to and display along physical objects.

These approaches rely on progress being made in several technologies. There is a need for advances computer vision algorithms to track physical objects without the need for orientation sensors. These algorithms also have to support the limited computing power of mobile devices. MR technology has to become more mobile. Web technologies have to find ways to reliably extract data from semi-structured sources. However, given the interplay between physical and digital objects enabled by our early prototype, we consider this a worthwhile area for further research.

Acknowledgements

This project has been enabled and funded by the Cluster of Excellence “Image Knowledge Gestaltung: An Interdisciplinary Laboratory” (EXC 1027) at the Humboldt University of Berlin.

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