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Look Inside: Understanding Thermal Flux Through Augmented Reality

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ABSTRACT

The transition from high school to university is an exciting time for students including many new challenges. Particularly in the field of science, technology, engineering, and mathematics, the university dropout rate may reach up to 40%. The studies of physics rely on many abstract concepts and quantities that are not directly visible like energy or heat. We developed a mixed reality application for education, which augments the thermal conduction of metal by overlaying a representation of temperature as false-color visualization directly onto the object. This real-time augmentation avoids attention split and overcomes the perception gap by amplifying the human eye. Augmented and Virtual Reality environments allow students to perform experiments that were impossible to conduct for security or financial reasons. With the application, we try to foster a deeper understanding of the learning material and higher engagement during the studies.

Index Terms: H.5.m [Information Interfaces and Presentation]: Miscellaneous

1 INTRODUCTION

Students of the academic disciplines of science, technology, engineering and Mathematics (STEM) struggle with the change from high school to universities. This change results in general high dropout rates. In the field of physics, constant dropout rates of up to 40% in the first two semesters are common [3]. This circumstance urges continuous innovation, investigation, and evaluation of new educational concepts like interactive engagement with peer instructions [2] or replacing lecturing sessions with student group problem solving.

Over the last decade augmented and virtual reality hardware and software matured and are now entering the consumer markets. Cheaper hardware and low prototyping cost accelerate the developing process. Recently we see more and more mixed reality applications targeting learning scenarios to stimulate self-paced learning, and for the first time, we see mixed reality applications being explored beyond the lab. However, in the field of education and knowledge-sharing an in-depth analysis of mixed reality learning applications reveals that they have diverse effects on the students' performance [6].

One of the fundamental problems many students in the field of physics face is the fact, that the concepts and laws are based on quantities that are not directly visible to the human eye. Electricity, for example, is one of this abstract concepts. We are able to measure resistance, current, and voltage with the multimeter but can not directly visually perceive these quantities. Beheshti et al. developed a tablet-based augmented reality application and visualized electrons flowing through a circuit to foster a better understanding of electrical circuits [1].

In this work, we present our development of an augmented reality application enabling students to observe the heat flux through a

Figure 1: Student conducting the thermal flux experiment. Levitating graph and false-color temperature representation are only visible through augmented reality display.

metallic rod. The rod is heated on one side with a cartridge heater while cooled at the other by a standard CPU fan to generate a temperature gradient. While wearing augmented reality glasses students can visually perceive the temperature using a false-color representation overlaying the metallic rod. Besides, a graph, depicted in Figure 2, is floating above the experiment setup visualizing real-time temperature values.

We contribute with an architecture description of an augmented reality application to enhance human perception in physics class. In addition, we present future research opportunities in the field of experimental teaching courses.

2 PROTOTYPE

We tailored our augmented reality application to teach heat conduction in metals for an introductory laboratory course in thermodynamics for physics on top of an existing experiment. Previously, students were required to take snapshots with a handheld thermal camera to acquire data and do an offline analysis. With our application, students get real-time feedback and enhanced data visualization of the experiment and can observe the thermal flux. Fist results of a user study using the prototype showed a small positive effect of augmented reality on students performance with regards to acquired knowledge in thermodynamics [7].

2.1 System Architecture

Our system comprises the thermal experiment itself, an infrared camera attached to a server and an augmented reality display acting as a client. Our simple server-client architecture supports multiple users at the same time to enable collaborative experiment execution. An overview of all components is depicted in Figure 3.

The thermal experiment itself consists of several metallic rods made of aluminum, copper or brass. A power adapter supplying 12 volt is used to control the temperature of one end of the metallic rod. Further, there are insulated rods to generate different thermal flux properties.

The thermal cameral is placed central in front of the metallic rod to capture real-time temperature values. These are forwarded to the

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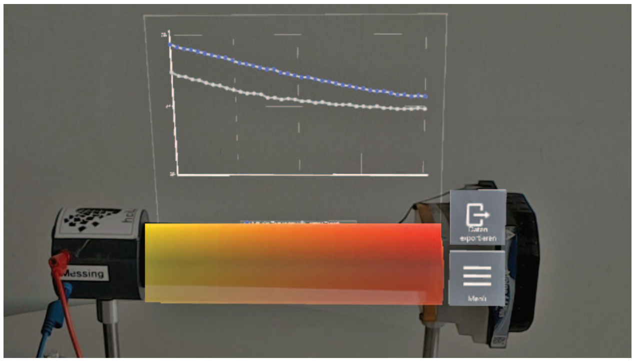

Figure 2: Students view with all augmentations showing false-color temperature distribution and graph with real-time values (blue) and latest export (gray) as reference.

server for further processing. We utilize an Optris PiConnect 160 infrared camera with an optical resolution of 160 x 120 pixels.

The infrared imager is connected via USB to a computer running a server application and image processing pipeline. The captured infrared video feed is analyzed and based on the temperature signature the metallic rod is registered within the data. The sampled temperature data is recorded and sent wirelessly via a simple communication protocol to the client on request.

The augmented reality display is in charge of rendering the false-color representation on-top of the metallic rod as well as plotting the floating graph above the experiment setup representing the real-time data. To enable correct augmentation of the experiment, the AR display needs to register the setup in space. In our prototype, we specifically utilize the Microsoft HoloLens since it is fully self-contained with build in client capabilities. To register the experiment, we use the Vuforia framework, the environment facing camera of the HoloLens and printed markers attached to each metallic rod to identify the experiments' location in space as well as the ID and material of the rod itself. Finally, the augmented reality display gives in-situ hints and additional information to guide the students through the experiment.

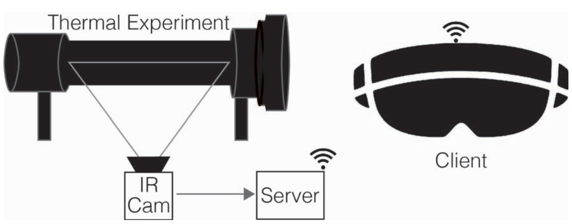

Figure 3: Prototype architecture comprising a server streaming real-time experiment data to the HoloLens client.

2.2 Experiment Execution

To actually run the experiment with augmentations the student is required to set up the experiment sample. The metallic rod sample needs to be placed in front of the thermal camera. In addition, the power supply needs to be connected to the heating and cooling element, and the thermal camera to the server that runs the service. Then the student can put on the HoloLens and start the application as well as switch on the power supply to start the experiment. On the first launch, the student is required to scan the marker attached to the rod to ensure a precise alignment of the augmentation. Afterward, it is possible to observe the heating process and thermal flux. During that process, students can export a snapshot of the current temperature distribution to enable later analysis and theoretical calculations. All interaction is facilitated with point-and-click interactions on virtual buttons arranged next to the experiment. The interface further allows the student to display or hide different visualization or restart the registration process of the experiment location if the experiment got moved to a different position.

3 Discussion and Future Work

The proposed system enables students to perceive physical phenomena in a novel and more relatable way, increasing both their interest and understanding of experiments. We believe that a long-term study will provide insights on the effects that augmentation can have on learning. Additionally, we see research potential in finding alternative implementations based on more accessible hardware. In this sense, the deployment using handheld AR devices (even smartphones) can result in larger scale and more affordable setups.

We envision that future iterations of this contribution might consider different experiments on different physical effects, covering various fields of physics. We argue, as also proposed by Finkelstein et al. [4], that substituting physical experiments with carefully considered mixed reality environments can outperform real-world experiments. Students can particularly benefit from simulations and a more extensive variety of experiments since virtual adaptations of the experiments ins size, shape, material, or the like will be inexpensive [5].

4 Conclusion

Many students struggle with understanding abstract physical concepts since they rely on non-visible quantities. In traditional experiments, students often do not get real-time data visualization. Analysis and calculations are mostly done offline. In this work, we have presented our prototype of an augmented experiment visualizing thermal flux in situ. The prototype allows hands-free interaction and supports multiple users to enable students to collaborate. Although providing advanced visualization, our prototype remains a simple to operate augmented reality system. In the future, we will conduct more qualitative and quantitative user evaluations to improve learning effects and understand what physical probes are necessary to learn effectively.

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