DEMO: Preparation for Future Learning: Augmented-Reality Enhanced Interactive Science Labs

Orkhan Amiraslanov
DFKI GmbH
Kaiserslautern, Germany
orkhan.amiraslanov@dfki.de

Paul Lukowicz
DFKI GmbH
Kaiserslautern, Germany
paul.lukowicz@dfki.de

Hamraz Javaheri
DFKI GmbH
Kaiserslautern, Germany
hamraz.javaheri@dfki.de

Sizhen Bian
DFKI GmbH
Kaiserslautern, Germany
sizhen.bian@dfki.de

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Abstract
This demo presents an interactive experiment environment for physics and electrical engineering students and aims to provide a deep insight into the basic electrical theories (i.e Ohm's, Kirchoff's law) using real-time sensing system with augmented-reality (AR) visualization enhancements. To this end, a system was designed to measure the current, voltage, AC frequency and RFID based 2D positioning. A mixed reality glass, HoloLens, was used to provide the visualization and augmentation. An application is designed for HoloLens to provide different visualization of nodal measurements and detected circuit schematic. Using this interactive experiment setting, the goal is to reduce the cognitive load of a learner while allowing more enjoyable and intuitive learning experience.

ACM Classification Keywords
K.3.1. [Computers and Education]: Computer Uses in Education

Author Keywords
Augmented Reality; Learning; Electronics Lab; Learning; Physics Experiments

Introduction
"A moment's insight is sometimes worth a life's experience"(Oliver Wendell Holmes (1809-1894)). Providing a

Figure 1: Experiment Materials

learning environment such that learners would mainly focus on understanding the underlying principles in an intuitive and hands-on ways were always a big challenge, and the moment of combining the theory and practice has always been the Achilles heel of the learning system. Aim of this project is to improve the understanding of basic physical laws in electrical circuits for science and engineering students using Augmented-Reality (AR) technology by superimposing real and digital worlds. To achieve this, custom hardware and software were designed to aid an interactive, AR enhanced experiment lab setup for introductory electronics classes.

Related Word

Not everyone is good at learning from books while they usually prefer visual and hands-on learning. Visual perceptual learning has proven to be more effective [5] method. Based on earlier works [1] we can clearly see how AR technology enhances traditional learning in an educational settings. It provides visual insight into hard-to-understand topics and concepts. AR in educational settings guides [2, 3] the learners with visuals and interactive tools while helping them to better grasp the theory with graphs and diagrams. AR could also help students to learn the course content by providing a prosperous setting that mirrors the real-world scenarios, and such new knowledge could be grasped with less effort [4], while keeping the students interest in the topic.

System Description and Architecture

Our proposed system consist of two main parts: basic component boxes and HoloLens application (see Figure 1). Each component box contain basic circuit elements such as resistor, capacitor, and etc. which could be changed depending on the experiment design. These boxes acts as building blocks of circuits used in introductory electronic course and they can be interconnected via 3.5mm sockets to form a closed circuit. In addition to the base component in each box a simple sensing and cable identification front-end, an RFID based locationing and a wireless communication system have been added to each box. A Complementary HoloLens application is designed to provide a real-time augmented visualization of measured elements and circuit schematic using data collected from the component boxes. Overall system architecture is shown on Figure 2.

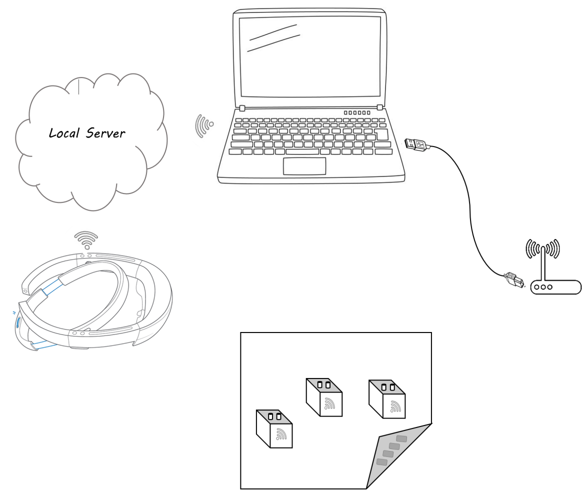

Figure 2: Abstract view of components used in proposed setup for interactive physics experiment

Measurement Front End and Cable Identification

Sensing front-end in each box is designed to measure the current, voltage and identify cables connected to each box. Current measurement is achieved by placing a low value shunt resistor (0.1 Ω) in series with the base component and measuring voltage drop across it. Digital current measurement IC (INA219) is used to measure the bidirectional

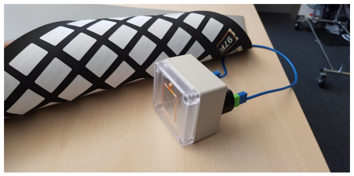

Figure 3: RFID mat and component box

current flowing through the component. Voltage drop across the circuit element is also measured with the aid of a simple circuit composed of a resistive voltage divider and an operational amplifier (op-amp) based level-shifter (to compensate for negative voltages). Designed measurement front end is able to sample up to 500 Hz, which also enables to calculate AC frequencies up to 250 Hz.
To construct the circuit diagram on the AR environment dynamically we need to know how the basic component boxes are interconnected. To achieve this we need to label each cable and later identify it. We have incorporated a simple method using 3.5mm TRS audio jacks and plugs. Tip of this connector is used for interconnecting the boxes electrically, but the ring and sleeve part is connected to a resistor inside the plug, and when a student plugs the jack into a socket the internal resistor completes a voltage divider circuit and our measurement front-end identifies the cable.

Real-time RFID based 2D Localization
The aim of this project is to provide augmented visualization of measurements attached to each component box to ease the learning process. Thus, tracking of each component box was a requirement. As it was previously stated, Microsoft HoloLens glass was used to provide the augmented reality visualization. Since the marker based tracking using HoloLens's built-in camera and Vuforia was not stable and convenient enough for project purpose, therefore, a new method is proposed to maintain the tracking of each component box. A small RFID reader is attached to each box and RFID sticker array are added underneath the ESD mat (see Figure 3), which is a typical table cover for Electronics labs. This method provided rock-solid tracking with positional accuracy of $\pm 5\ cm$ (see the accompanying video). RFID stickers under the mat are hard-coded with unique positional information (X-Y coordinates). In each box there is also a MEMS accelerometer. This sensor is used to put the RFID front-end into sleep mode and activate the system only when it's slightly moved, thus saving the battery life and increase the run time of the whole system.

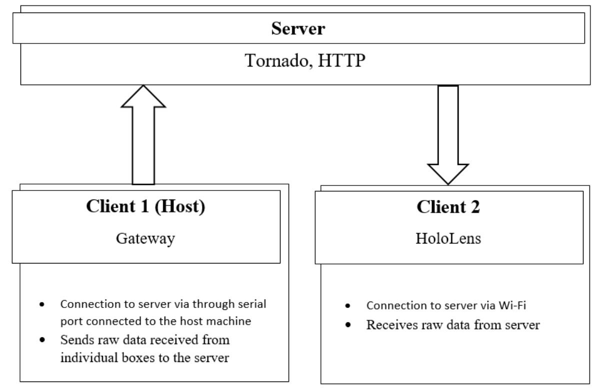

Figure 4: Server-Client based system architecture

Wireless Component-box Network
Main microcontroller in each box puts most of its internal and external peripherals into sleep mode to save energy. Depending on the required sampling rate it wakes up, reads necessary sensing elements and transmits the raw sensor data over 2.4GHz RF link to a gateway. Gateway then collects data from all the available boxes and forwards it to a PC. Collected data then gets filtered and shared on the local HTTP server written in Python. The system is constructed in a star network and current range is up to 20 meters radius.

The server is based on server-client architecture using Tornado HTTP framework. The gateway is connected to the host machine through serial port. Thus, the values written on serial port is read and published on local network (Figure 4).

HoloLens Application

An application was designed in Unity3D game engine to provide different types of visualization of the data measurements attached to each box. The application runs with 60 frame per second. In each frame measurements and positional data of all boxes are fetched from local HTTP server maintaining real-time and smooth visualization.

The position information of box is used to move the relative graph as box moves. The center of RFID math is set to the center of world coordinate system, hence the position of each box is calculated relative to the world coordinate system.

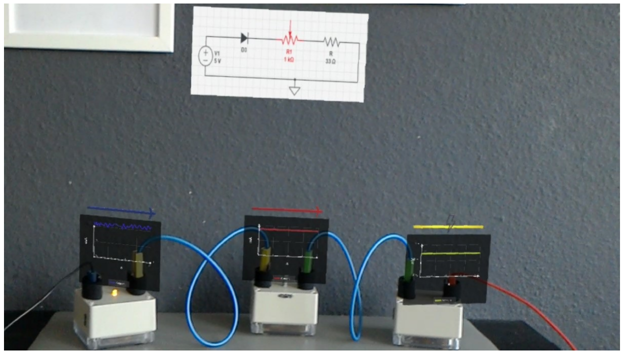

Figure 5: A snap from inside of the HoloLens application

The voltage and current measurement is displayed in each graph attached to box as line graph. To reduce the cognitive load on the student while learning, different graph visualizations and color schemes are available to choose from. Each cable has unique id which is read when it is plugged to the boxes. The schematic of circuit interconnection is dynamically calculated and presented to the user to provide a better understanding of serial and parallel connection concepts. The current flow direction is also among the features which is presented to the student (Figure 5).

Discussion and Conclusions

We strongly believe that introduction of AR into classrooms will greatly enhance the learning experience of students and our system can be crucial for introductory electronics lectures.

At this moment we have not carried out an actual user study, but our preliminary test runs show that the system is very helpful as a learning aid and it has great potential for educational purposes. Once we produce enough boxes in higher quantities then we will conduct more extensive user studies with freshman physics and electronics students.

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