Chapter 1

WIRELESS DISPLAYS IN EDUCATIONAL AUGMENTED REALITY APPLICATIONS

Hannes Kaufmann and Mathis Csisinko
Institute of Software Technology and Interactive Systems
Vienna University of Technology, Vienna, Austria

1. Introduction

Augmented Reality (AR) as defined by Azuma [1] does not pose restrictions on output devices to be used for AR. Starting with light-weight notebooks and ultra mobile PCs, recently smartphones became favorite AR output devices. They represent a class of self contained computing units, providing (usually limited) computing power as well as input and output peripherals - all in one device.
In contrast to that are output devices without a general computing processing unit which rely on external source to create and transfer image data. The latter are of interest in this work.
In this chapter we present wireless technologies that can be used to transmit uncompressed stereoscopic video signals to wireless displays in real time. We introduce two output devices, a stereoscopic head mounted display (HMD) and a TFT display module. Both of them have been adapted to act as wireless receivers in order to display wirelessly streamed AR content. Next we focus on advantages of wireless displays for educational AR applications. By way of example two educational AR applications are presented which were used to demonstrate and test wireless displays. A number of teaching scenarios are described where teachers and students greatly benefit from the use of wireless displays. We briefly summarize the results of our observations while developing and evaluating these displays.

1.1 Motivation

If many users collaborate in a virtual environment, personal displays (e.g. head mounted displays) can be used to deliver user specific views or context sensitive information to each user privately. The reason why we started working on wireless displays is that in [2] we presented a low cost hardware setup that allowed attaching 12 and more HMDs to a single PC. For evaluation purposes a collaborative, educational, augmented reality application was used by six students simultaneously who were wearing HMDs. These devices were attached to a single PC which rendered 6 views of the application at interactive frame rates. The final evaluation revealed usability problems. A major hindrance for practical usage of such a setup was the number of cables of HMDs. Given a wireless tracking solution (e.g. optical tracking), the number of cables is at least equivalent to the number of displays. Cables lie on the floor and tend to get tangled as soon as participants start to move. Users have to be very careful not to stumble over cables. As a further consequence movement and interaction is restricted and the number of displays/users has to be limited. Therefore we started to look into wireless solutions to deliver personalized content to users.

1.2 Trend towards Wireless Clients

In recent years there is a trend towards smart mobile computing units. Popular examples of such mobile devices are nowadays smart phones, e-book readers and tablets. Technical advances in performance lead to increasingly powerful devices while minimizing size and weight.

However, computing power of mobile devices is still inferior to desktop computer systems. Provisions to mobility requirements (size, weight, battery lifetime) are limiting factors for computing performance. In particular, there is a tradeoff between mobile device computing power vs. mass, form factor and power consumption. Handheld devices like smart phones have superior mobility features than netbooks and ultra mobile PCs (UMPCs). However, comparing the same devices in terms of computing performance, netbooks and UMPCs are ranked higher than smart phones.

Consequently, mobile computing units are not usable under the precondition that computing (and graphics) performance must be similar to desktop systems. This is exactly the case in real-time Virtual Reality (VR) application scenarios. For instance if we consider medical VR/AR applications with volume visualizations of large datasets, physics simulations or other high end application areas, the performance of mobile computing units will not be sufficient compared to desktop systems for many years to come.

In order to circumvent limitations of current autonomous mobile devices we follow a different approach: High fidelity computing is performed on ordinary state-of-the-art desktop systems and its output is transferred wirelessly to mobile display devices. By this means computing power does not affect size and weight of output devices. This approach is closely related to thin clients in the area of terminal computing.

In the area of terminal computing, a thin client is a computer terminal with the main purpose of providing a graphical user interface to the end user. Computing power and functionality are provided by a server. Lately, the trend towards lowering computer infrastructure costs lead to the introduction of so called zero clients. While thin clients still require some local processing power and locally installed software, zero clients eliminate the need for locally installed software and connect directly to servers which are located elsewhere. Zero client hardware typically consists of a small box that connects to a keyboard, mouse and monitor. A zero client is able to connect with the server over a wired or wireless IP network.

In PC gaming a live streaming service (OnLive) became available recently. Latest computer games run on servers in the OnLive data center and the image output produced by these games is streamed in real time to PCs of home users at interactive frame rates. Internet connectivity with high network bandwidth is a prerequisite.

These examples illustrate that clients which simply display (wirelessly) streamed content are becoming more frequently used. Maintenance costs are lower because only servers need to be maintained, software synchronization between multiple clients to keep software versions current is not necessary. Output devices without computing power can be produced at much lower costs, have reduced power requirements and can be very light weight. These are important criteria in AR environments as well.

With the technologies presented in section 3, existing standalone output devices can be converted into wireless displays. This encompasses head mounted displays, LCD/TFT/OLED display modules, video projectors and more.

2. Technological Background

2.1 Requirements

There are a number of requirements for wireless transmission of display signals. Virtual environments are real-time applications where users typically walk around, adapt their viewport and manipulate the surrounding environment. It is expected that the effects of these actions are perceivable immediately because the user depends on feedback. Hence, timing is very crucial, especially for visual feedback, the most dominant form of feedback. Therefore, low transmission latency is mandatory. High latency can cause a number of side effects; the degree of immersion and the feeling of presence decreases. The same can be observed if there are (temporary) failures in visual feedback. Thus, wireless transmission must make use of reliable communication channels.

Furthermore, it is desired to achieve the highest quality of display signal transmission possible. Unfortunately high quality graphics transmission at interactive frame rates requires quite high bandwidth. For example, a stereoscopic HMD running at a resolution of 800×600 at 24 bits color depth with 85 Hz frame rate (42.5 Hz per eye) requires nearly 1 Gbps. This is approximately two decades higher than digital TV program broadcasting, where the data rate is around tenths of Mbps.

Contrary to digital TV program broadcasting we cannot use sophisticated compression algorithms in order to cope with limited bandwidth. There are two main reasons:
First of all, transmission delays in TV program broadcasting are not as crucial as in AR application scenarios where low latency has to be enforced. Unfortunately, compression and decompression takes some time and therefore latency would increase.
Second, lossy compression algorithms cause visual artifacts on the receiver's side. This behavior is undesired especially in stereoscopic display signal transmissions which are being used for HMDs. Reconstruction artifacts in video frames may disturb the user. If no further provisions are taken into account, reconstruction errors between display frames for the left and the right eye will differ in general. Consequently, this will affect the aligning process in the human vision system in a negative way.
In summary we require a wireless solution with high bandwidth and low latency. In December 2009 Sensics conducted a worldwide survey (details in [3]) in order to evaluate user requirements for wireless HMD signal transmission. According to the results, both low latency and a refresh rate of 60 frames per second (or higher) were considered as top priority. The capability for true stereoscopic viewing and the ability to use multiple HMDs simultaneously had also high ranking.

2.2 Wireless Technology Overview

Our solution is based on the WHDI standard from AMIMON [4]. This technology is primarily targeted on consumer electronics, in particular HDTV, and establishes wireless HDMI signal transmission. HDTV resolutions require bandwidths in the range of about 1 Gbps up to 3 Gbps and WHDI is able to provide these data rates. Stereoscopic video signals (HMDs) with the demand for increased frame rates have bandwidth requirements close to these figures (approximately 1 Gbps, as mentioned before). The WHDI solution uses multi-input-multi-output (MIMO) technology and establishes wireless communication over the unlicensed 5 GHz frequency band.
In general the bit rate of a wireless connection is not constant over time. The WHDI implementation includes technology to adapt to the current conditions utilizing prioritization of more important components of the video signal. This differentiation between more and less important components include more vs. least significant bits (MSB vs. LSB) of video pixels, lower vs. higher spatial frequencies and luminance vs. chrominance information. More important parts are encoded and modulated in a way that correct reconstruction on the receiver's side is more likely than for less important components. This guarantees that even in the case of decreasing wireless channel capacity communication does not break down immediately and the video signal can be reconstructed, although in lower quality since less important components might have been lost. We did not observe such cases since we were not operating on the upper bandwidth limit.

There exists a competitive standard, called WirelessHD operating on the 60 GHz band with 7 GHz channel bandwidth. It features data rates up to 4 Gbps with a theoretical limit at 25 Gbps.
Furthermore there is a commercially available wireless solution for HMDs. Sensics offers a wireless link option for its HMD products. It is based on Wi-Fi wireless N technology and MPEG4 H.264 video compression. According to the specification a system latency of below 32 ms is maintained. However, Sensics is specialized in HMDs with wide field of view and high display resolutions (e.g. 1280×1024 pixels, 1920×1200 pixels). Thus its products are more targeted on a high price market and probably not affordable for every customer.
Finally for all these different wireless solutions there is no official statement in the specifications about display resolutions with frame rates above 60 Hz. Higher frame rates are required especially for HMDs operating in page-flipped (frame sequential) mode. Due to the fact that video frames are split between left and right eye, each eye perceives images at a frame rate which is only half as big as the display signal refresh rate.
Hence we had to test higher frame rate capabilities in our hardware setup in order to check whether we get acceptable results for frame sequential HMD signals.

3. Hardware Setup

The first-generation WHDI devices (ZWD-2500, see
Figure 1 left) that we used in our setup were produced by Zinwell. The slim dimensions (180×140×39 mm³) of the receiving device and its mass of about 220 g were acceptable for our prototype solution. Contrary to the mobile receiving device, the transmitting device is not carried around by the user. Thus, mass, size and power consumption characteristics are not as critical as for the receiving device.
The transmitter (ZWD-2500T) contains four input ports (two HDMI and two sets of RCA video component ports). It selectively provides a wireless link of one of its input signals to the receiver (ZWD-2500R). On the receiver's side the transmitted signal is output by an HDMI port. Additionally, wireless transmission covers audio and remote control signals as well. However, these features were not used in our setup. These first-generation devices seem to have a bandwidth limitation of approximately 1.5 Gbps. Officially 1080p resolution is supported up to a frame rate of 30 Hz, whereas the second-generation WHDI devices support 60 Hz frame rate as well (approximately 3 Gbps data rate).
For our device setup latency is specified as being less than 1 ms, which is excellent for AR applications. Furthermore, it is possible to operate multiple pairs of WHDI receiving/transmitting devices simultaneously. During initialization the devices automatically negotiate radio channels but there is also the option to override them manually. In the latter case the devices offer selecting one out of ten different radio channels. In our tests we used automatic negotiation and successfully operated three pairs of WHDI devices.

Transmission range is specified as up to 20 m in a line of sight condition, which is reduced to a maximum of 10 m in cases beyond line of sight. This is sufficient and compatible for our indoor tracking scenarios.

True wireless display devices require mobile power support as well. Fortunately, light-weight accumulators are available nowadays. We have chosen Lithium-ion polymer (LiPo) accumulators, which evolved from Lithium-ion batteries. Compared to other kinds of mobile power sources they feature very high power capacity, low weight and small form factor at the same time. Hence, they can be found in various mobile electronic devices (e.g. music players) and are popular power supplies for radio-controlled scale aircraft models as well.

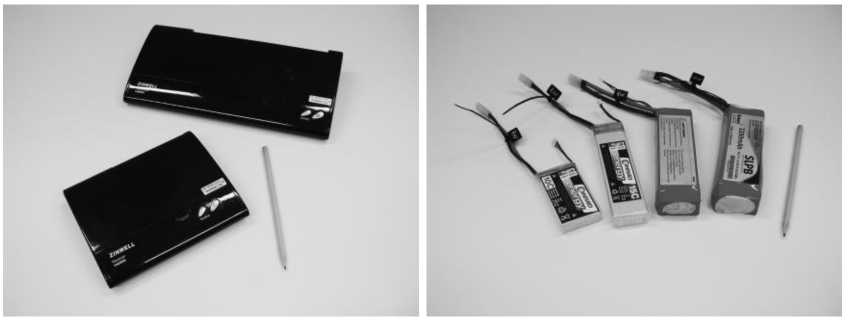

Figure 1. WHDI devices (left), LiPo accumulators (right).

The WHDI receiver must be supplied with a voltage of approximately 5 V. We use LiPo accumulators (see Figure 1 right) with a voltage of 7.4 V. This voltage is reduced to about 4.8 V by a regulator module in order to ensure electrical compatibility with the receiver. The masses for the LiPo accumulators used in our setups are between 100 and 400 g.

3.1 Wireless Head Mounted Displays

With the introduction of low cost head mounted displays, prices of HMD-based mixed reality setups dropped considerably. Two HMD models were tested in our prototype solution (see Figure 2):

The Sony Glasstron model LDI-D100BE is an optical see-through device with a LCD display resolution of 800×600 pixels (each eye) at a maximum frame rate of 85 Hz (42.5 Hz per eye). This HMD supports page-flipped (frame sequential) stereoscopic viewing. The head-worn display unit is connected to and controlled by a power supply box. Power is supplied either by an AC power adapter or by manufacturer specific lithium-ion battery packs. The operation time for the battery packs we used in our setup (with a capacity of approximately 5.4 Ah) is about three hours. The dimensions of the power control box are approximately 54×47×160 mm^3 and its mass specified as about 260 g - excluding any battery

pack which might be mounted on and connected to the box. For better wearability we mounted the display unit on a light-weight bicycle helmet. Unfortunately this HMD model is not produced any more.
The eMagin Z800 3DVisor incorporates two 800×600 pixels OLED displays and can be driven with up to 85 Hz frame rate as well. The Z800 consists of a head-worn display unit and a control box, similar to the Sony Glasstron. However, there is no optical see-through option for this device. Power must be supplied either by connecting an external power adapter (5 V) or an USB cable.
Stereoscopic output can be a bit troublesome with the Z800. In the case of a wired VGA cable connection to an nVidia graphics card, the Z800 automatically detects frame sequential stereoscopic display signals by inspecting proprietary control signals. However, this is superseded with new graphics cards which do not support this mode anymore. Alternatively, switching into stereoscopic mode can be performed manually but this requires a USB connection. In our wireless solution automatic detection of frame sequential stereoscopic display signals is not possible. Therefore, we utilize certified wireless USB (CWUSB) technology. Our CWUSB setup consists of a pair of USB devices, namely a host and device dongle. The device dongle is connected to the control box and must be externally power supplied, which provides power to the control box as well.

Figure 2. HMD models: Sony Glasstron (left), eMagin Z800 (right).

Both HMDs expect VGA signals. However, the WHDI receiver delivers an HDMI video signal, which is incompatible to VGA. Therefore, an HDFury2 device is connected in between in order to perform the required conversion of the video signal.
Unfortunately, the documentation of the WHDI devices does not officially state whether other resolutions than HDTV are supported. Video signal transmission at a resolution of 800×600 pixels and the HMD’s maximum frame rate of 85 Hz (approximately 1 Gbps data rate) fails, even though other supported HDTV resolutions require significantly more communication bandwidth. Hence, this is an indication that the problem is caused by technical limitations other than wireless transmission channel bandwidth constraints (approximately 1.5 Gbps as mentioned before). Nevertheless, we were able to demonstrate successful operation of our device setup at a reduced frame rate of 72 Hz (approximately 0.8 Gbps data rate).

The final hardware setup with all components is shown in
Figure 3. The interconnecting cables provide power and video signals to the HMD. As mentioned before WHDI devices support wirelessly transmitting stereophonic audio signals as well. In addition to that, both HMD models contain earphones. Providing stereo sound requires an additional cable connection between HMD control box and WHDI receiver.

Figure 3. HMD setup assemblies: Sony Glasstron (left), eMagin Z800 (right).

Power consumption of the WHDI receiver was measured with up to 1.5 A and approximately 1.2 A on average. This means that even a LiPo battery with a low capacity of 1.6 Ah is able to supply power to the receiver for more than one hour. This figure exceeds the limiting factor of cybersickness symptoms. Various studies (e.g. [5]) recommend limiting the use of HMDs to 20 to 30 minutes per session in order to avoid symptoms of cybersickness. Moreover, operating hours can be increased with larger capacities. We used LiPo accumulators with capacities of 3.2 Ah respectively 5 Ah. All mobile components except for the head-worn display unit fit in a shoulder bag (see

Figure 9 and Figure 10). This is acceptable for a prototype solution. However, if there is further demand in the future, size and mass of WHDI receiver and HMD control box need to be reduced. Obviously all components could be integrated into a single device. This would eliminate long cables interconnecting subcomponents and would allow for further reduction of size and mass.
Instead of using battery packs, a single LiPo accumulator with a voltage of 11.1 V could supply power to all devices for the Sony Glasstron.
Furthermore, the CWUSB connection in the eMagin Z800 setup could be eliminated as well, if the necessary signals for the control box were integrated into the WHDI channel. Similar to the unused feature of our WHDI device to transmit remote control signals these signals would occupy only a tiny fraction of transmission bandwidth.

3.2 Wireless Handheld Display

We tested our wireless solution with a commercially available TFT compact module. This kit is an all-in-one display solution containing all necessary components for driving a 12.1 inch TFT screen mounted to a metallic frame (see

Figure 4). Its highest resolution is 1024×768 pixels. The module must be supplied with power from an external source (12 V) and contains an electrical port for connecting either DVI or VGA sources. Its dimensions of 260.5×204×21 mm³ are suitable for mobile displaying applications. Due to the metallic frame the mass is approximately 1 kg. However, if there is a demand for reduced weight this could be further reduced in the future.

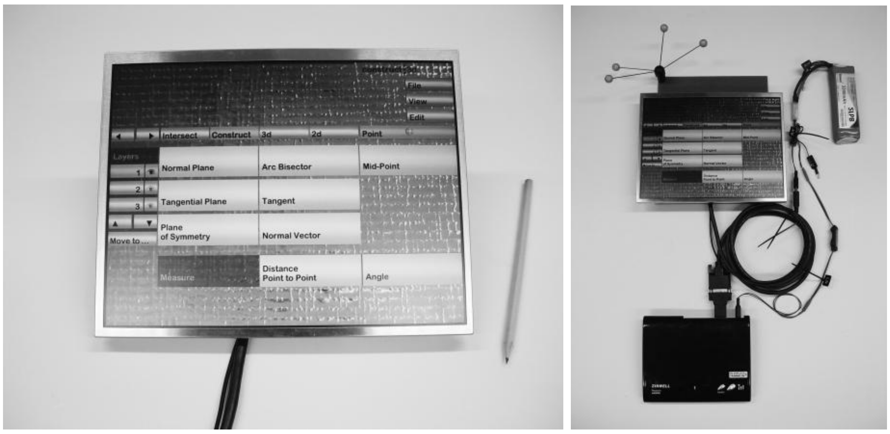

Figure 4. TFT screen (left), final setup assembly (right).

The display module requires electric current of approximately 1 A. Summing up the power consumption of the display module and the WHDI receiver, a battery capacity of 3.2 Ah is sufficient to supply power to both devices for more than one hour by using a single LiPo accumulator. If we would increase the capacity to 5 Ah, the operating time would be extended to at least two hours. The slightly reduced voltage of the mobile power supply (11.1 V) had no negative side effect on operation.

Again due to lack of support, video signal transmission at a resolution of 1024×768 pixels and the display's maximum frame rate of 75 Hz failed. However, there was no problem supplying the display with a frame rate of 70 Hz (approximately 1.3 Gbps data rate).

4. Areas of Application: Examples in Education

A number of studies have investigated orientation and navigation in virtual environments through which participants navigate using joysticks or other devices [6-8]. These applications have shown to be very fruitful for studying orientation processes; however they are still restricted to an essentially non-spatial format of presentation. In these studies participants see the environment on a screen. Therefore many important cues that are automatically encoded during real-life locomotion in a real environment are missing [9, 10]. The AR applications and scenarios that we are presenting try to overcome this problem. Participants can move around the objects they are working on and can virtually “touch” and manipulate them.

The simultaneous sharing of real and virtual space in AR is an ideal match for computer-assisted collaborative educational settings. Overviews of educational AR and VR applications, use cases, requirements and potentials are given in [11, 12], [13] (chapter 2) and [14].

Educational applications are typically characterized by additional specific requirements that are unique to this domain.

- For real applicability in classroom, educational AR applications ideally support a large number of users.
- They allow simultaneous interaction of at least two users, for instance teacher and student.
- They have to be robust and easy to use. Students usually expect technology to work and loose motivation quickly if immature technology negatively affects their work.

In general users do not want to be hindered by cables. Wireless displays seem to assist in fulfilling all of these requirements.

In order to demonstrate maturity, robustness and usefulness of wireless systems as described above, we used these output devices in existing educational applications. In the following we briefly describe educational applications that have been evaluated. Section 5 details teaching scenarios where wireless technologies are beneficial.

4.1 Construct3D

Construct3D [13, 15] is a three dimensional geometric construction tool specifically designed for mathematics and geometry education. A collaborative augmented reality setup is utilized with the main advantage that students actually see three dimensional objects in 3D space which they previously had to calculate and construct with traditional methods. Augmented reality provides them with an almost tangible picture of complex three dimensional objects and scenes. It enhances, enriches and complements the mental images that students form when working with three dimensional objects.

Figure 5. Students working with Construct3D.

The application supports multiple collaborating users wearing stereoscopic see-through head mounted displays providing a common, shared virtual construction space. Typically one PC with two graphic ports renders stereoscopic views for both users. Head and hands are tracked with millimeter accuracy using an iotracker [16] optical tracking system. This allows students to walk around objects and to view them from different perspectives.
Construct3D's menu system is mapped to a hand-held pen and panel interface, the Personal Interaction Panel (PIP) [17] (

Figure 6). The pen is used for operating the menu on the panel as well as for direct manipulation of the scene in 3D space. Augmented reality enables all users to see the same virtual objects as well as each others' pens and menus, therefore a user can provide help to a colleague if desired. The face-to-face setting allows for traditional pedagogic communication between teacher and students. Other setups for educational use have been reported in [13].

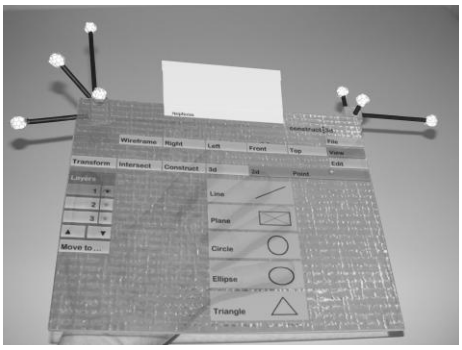

Figure 6. Construct3D's main menu on the PIP seen through an HMD.

Construct3D is based on the Studierstube software platform [18] as a runtime environment and for multi-user synchronization. The current version of Construct3D offers functions for the construction of 3D points and geometric objects. It provides planar and spatial geometric operations on objects, measurements, and structuring of elements into "3D layers". It supports generation of and operation on points (either freely positioned in space or fixed on curves and surfaces), lines, basic 2D and 3D objects, B-Splines curves, NURBS surfaces and surfaces of revolution. To mention just a few, the following geometric operations are implemented: Boolean operations (union, difference, intersection) on 3D objects, intersections between all types of 2D and 3D objects resulting in intersection points and curves, planar slicing of objects, rotational sweeps, helical sweeps, general sweeps along a path, surface normals, tangential planes, tangents and many more. A comprehensive overview of Construct3D is given in [13, 19].
The system features support for 3D *dynamic geometry*. All points can be picked and dragged at any given time. Experiencing what happens under movement allows better insight into a particular construction and geometry in general.
Construct3D was evaluated multiple times with over 500 users in total (students, teachers and experts) over the course of 5 years and is one of the longest developed educational applications so far. Three usability studies with more than 100 students have been conducted [5] and guidelines have been formulated regarding how to design AR applications for (geometry) education [20]. We studied how ongoing technological improvements can be integrated into an AR system and looked at pedagogical questions such as how to adapt contents of the current high-school curriculum to the new learning environment.

4.2 PhysicsPlayground

PhysicsPlayground [21] is an augmented reality application for mechanics education. Classical mechanics [22, 23] is the oldest discipline in the field of physics. It describes the common motion of objects that humans perceive in everyday life. The three fundamental laws of motion which were formulated by Isaac Newton (1642 - 1727) are traditionally part of the school curriculum as well as concepts such as force, velocity and acceleration.
It might be that physics in the traditional sense is sometimes taught in an abstract, jejune way and is therefore not very motivating for students. The result is that theoretical models behind physical phenomena are often misunderstood. However, conveying these concepts is of utmost importance since they are fundamental to physics.
PhysicsPlayground utilizes a recent physics engine (nVidia PhysX; survey in [24]) developed for the PC gaming market to simulate physical experiments in the domain of mechanics in real time. Students are enabled to actively build own experiments and to study them in a three-dimensional virtual world (

Figure 7). A variety of tools are provided to analyze forces, energy, velocity, paths and other properties of objects before, during and after experiments.

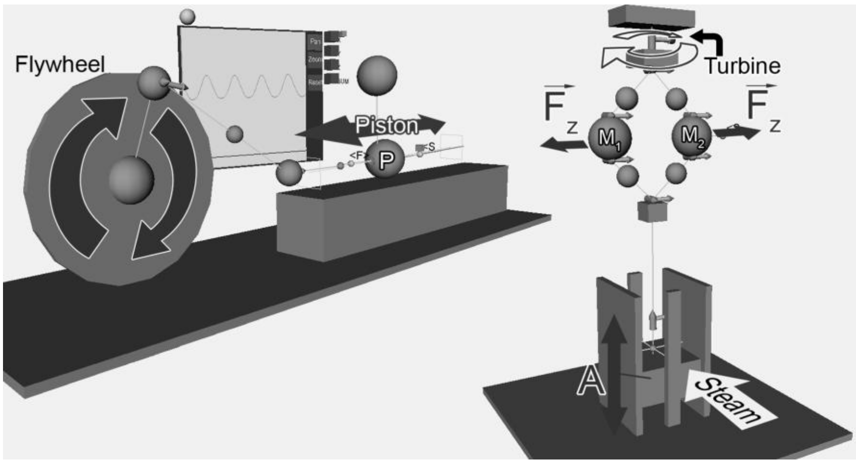

Figure 7. Left: An experiment simulating the motion of a car crankshaft. Right: A centrifugal regulator in PhysicsPlayground.

The overall hardware setup is equivalent to the one used in Construct3D. It supports multiple users, allows direct manipulation and free roaming around virtual objects. By using Sony Glasstron see-through head mounted displays students can see each other and their interaction devices. In

Figure 8 (right) several menu widgets are shown. Many of them have 3D icons placed on top which are animated when moving the pen over them. This is self-explanatory and clarifies their specific functionality.

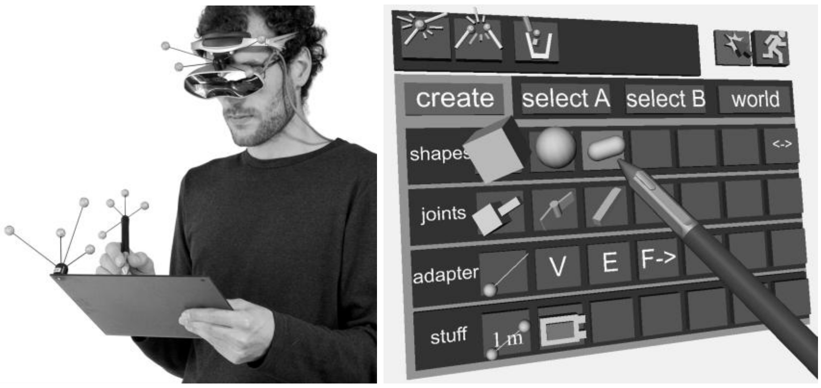

Figure 8. Left: Each user is equipped with input devices pen, PIP and head mounted display. Right: Example menu on the PIP.

Innovative teaching content can be studied to exploit the strengths of this immersive virtual environment. PhysicsPlayground serves as an example of how current technologies can be utilized to deliver a new quality in physics education.

5. Teaching Scenarios

During the work with educational AR applications such as Construct3D and PhysicsPlayground, teachers need to be able to communicate and to establish eye contact with students while interacting with the application. Therefore a teacher's output device of choice might be a mobile (tablet-like) display, a see-through HMD or a (stereo) projector. We pick a few regular teaching situations related to how AR has been used in previous Construct3D evaluations and how it could be used in future classrooms, to explain how wireless displays can be put to use.
In order to provide groups of users with an immersive experience exactly tailored to their point of view, all users (respectively their head and output device) must be tracked in space. Tracking a large number of users in such an environment is a problem on its own. It is obvious that any wireless form of tracking is preferred over a wired alternative because of the number of cables, limited freedom of movement leading to a rather tethered experience and other practical problems that would arise due to the cables. Optical tracking has proved to be an optimal solution in that case.

5.1 Scenario #1: Students Collaborate, Teacher Guides

In evaluations of Construct3D [5] we found that most students liked our standard dual-user setup best, when asked about different teaching scenarios. They had the choice between working together with a tutor (favored by 9.5 %), with a second student but without a tutor (4.7 %), or with a second student and a tutor (80.9 %). The latter scenario consisted of two users wearing HMDs (see

Figure 5) and a teacher who guided them.
Ideally students should be able to move freely to foster interaction and engagement. In addition their teacher needs freedom of movement to react to technical or cognitive problems and to communicate freely.
One option would be equipping the teacher with a wireless handheld display such as our TFT module. It is (optically) tracked and serves as a very flexible window into the virtual world. It can be operated single-handedly, frees the other hand for interaction with the application and the display can be put away (or attached to the belt of the teacher for instance) if not needed.
Alternatively the TFT display can be switched to menu mode. In menu mode the display serves as a menu (PIP) which can be used by the teacher to control the application and to help students in case of problems with the menu interface (see

Figure 9). We also built a wireless TFT touch screen module. Menu buttons can simply be pushed as known from touch interfaces; if using a pen to select and manipulate objects in 3D space, the pen can also be used to push buttons directly on the touch screen.

Figure 9. A wireless TFT display serves as a window into the virtual world for the teacher. Two wireless HMDs are used by students.

In this scenario we suggest that students use wireless HMDs so they can move around freely. In contrast to our work in [2] where wired HMDs hindered interaction and movement, wireless HMDs can be used by a larger group of students providing them with personalized views. This is of great advantage especially in applications such as Construct3D where users are encouraged to choose their own point of view. Some students tend to lie down on the floor (

Figure 5 right) or step on a chair to view geometry from different perspectives. They have the absolute freedom of movement within the tracking volume.

5.2 Scenario #2: Teacher Demonstrates and Shares

In this scenario a teacher performs an experiment or construction in 3D space with an output device of his choice (e.g. a see-through HMD). Each student possesses a wireless display module or students share a couple of displays to view and follow the instructions. The displays are tracked.

When students are called by their teacher to contribute to an experiment/construction, they are able to interact directly in 3D space. Similar to the capabilities of the teacher's interface in scenario 1, they can switch between a window into the virtual world and menu mode (Figure 10). Their classmates can watch on their own displays.

This scenario allows teaching a group of students, even a whole class in an AR environment.

Figure 10. The student (right) has to contribute to a task by using her wireless display while the teacher observes her work.

5.3 Experiences

No formal evaluations have been conducted with the wireless displays yet but experiences from observations can be reported. As soon as we changed our lab setup to reflect scenario 1, users of Construct3D and PhysicsPlayground started to move much more than before in an unconstrained, free way. Suddenly users seemed to have lost their inhibitions. They explored the virtual environment in a more active and natural way.

In the past we always had users who did not dare to move much. They seemed to freeze on the spot as soon as they put on an HMD and didn't even dare to turn their heads. With the introduction of wireless HMDs and a simple shoulder bag containing battery, control box and wireless receiver, there are no visible restrictions of movement anymore. Users do not perceive any limitations in range of movement.

Before starting to work in AR it takes up to a minute until a stable wireless communication channel is established. This is due to initial communication overhead between WHDI transmitter and receiver. In addition to that, as with any wireless technology, power supply of the wireless devices must be guaranteed in order to maintain a stable connection. Consequently, a number of mobile power sources have to be maintained. For intensively used system setups accumulators must be recharged on a frequent basis.

As mentioned before, the form factor of the mobile components could be improved or all mobile components could be integrated into a single device.

Since transmission latency of the chosen wireless transmission technology is very low (1 ms specified) there is no latency noticeable in any of our wireless devices. We do not expect that the described wireless technologies contribute to side effects such a cybersickness in an additional negative way.

Especially students will enjoy this freedom in movement - to lie down on the floor to look at objects from below or to step on a chair. It increases the fun factor and enhances the feeling of immersion.

6. Conclusions

In this chapter we present current wireless technologies to deliver uncompressed video signals at low latency to AR output devices. We have built head mounted and handheld prototype displays to demonstrate their use in educational applications.

In most application areas where head mounted or handheld displays are being used, wireless versions of these displays are favored over wired versions by end users. They allow unconstrained movement within the tracking volume, support untethered interaction and encourage active and natural interaction of multiple users.

At first sight this chapter seems to be targeted to indoor applications only. However, in case of outdoor AR applications, light-weight, flexible mobile devices without computing power could also be used together with wireless technology. The latest fourth generation cellular wireless standard 4G is specified to provide peak data rates of 1 Gbps. Long Term Evolution Advanced (LTE Advanced) is one example. This data rate is most likely not sufficient to continuously supply uncompressed image data to mobile wireless displays at interactive frame rates. However, long term a fifth generation standard is expected which will provide sufficient data rates to stream high resolution uncompressed video data to mobile devices. With the emergence of auto-stereoscopic display modules, stand alone displays could be used for 3D stereo output as well. A future of foldable, bendable, lightweight 3D output devices that receive video signals wirelessly is within reach.

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Index terms (alphabetically):

Wireless Displays
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WHDI