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Augmented Reality Active Learning (AnReAL) activities for teaching/learning motion concepts

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Abstract. From a physicist point of view, Virtual Reality setups are high-precision, low-cost, 6 degrees-of-freedom, high-speed, multiple-objects tracking devices. These setups prove to be very high-quality sensors that are well suited to be used in the physics laboratory for tracking in motion experiments. Augmented Reality can be achieved by attaching a stereo to the headset to allow students to see the 3D tracking of the experiment in the physical world. A series of Augmented Reality Active Learning (AnReAL) activities are presented, while also comparing this setup to more traditional ones, i.e. ultrasonic motion sensors and video tracking analysis software. Virtual and augmented reality setups, such as the presented one, are likely to prove very beneficial for information retention, following the emerging theory of embodied cognition.

1. Introduction

A Virtual Reality (VR) experience is truly convincing as long as the interactivity between the headset wearer and the software is precise and responsive. The basic VR interaction consists of the capability of the user to look and move around freely while always receiving the “correct” stereoscopic image in the headset. The “correctness” of the image is here related to the capability of the software to always be updated about the position and the rotation of the head of the user. From a physicist’s point of view, this means that a VR setup is basically a motion tracking device. This also extends to devices other than the headset itself, such as VR controllers which are used to interact with virtual objects: the capability of obtaining a good tracking of the controllers is the basis for such an interaction.

In the last 40 years, different hardware and software setups for motion tracking have been used in physics education research and have become common tools in the laboratory of physics. In particular, motion sensors have been used and studied in physics education research and proved to be very beneficial for students learning motion concepts: Thornton and Sokoloff [1] presented an entire motion curriculum based on active learning using what have now become traditional ultrasonic sensors (such as PASPORT motion sensors [2]). Video tracking software also proved to be a very powerful educational tool [3,4] and the recent widespread availability of smartphones only made it more accessible to everyone. Other authors suggested setups that make use of smartphone cameras to achieve a 3D object tracking [5,6]. More generally speaking, gaming devices are also very interesting for physics education as they are very advanced tools that are meant for mass production and targeted for a general public, so they are low-cost, reliable and easy-to-use devices. As an example, the Wii remote has been used for mechanics experiments [7,8,9]. Another very advanced tool revealed to be the Microsoft Kinect, being able to do 3D tracking of multiple objects [10,11].

In this work we show how common VR setups can be used in teaching/learning activities, comparing them to the aforementioned hardware alternatives and showing how their use can lead to many new opportunities. In particular, a stereo camera can be attached to the VR headset in order to achieve Augmented Reality (AR) through what it is called a *passthrough* visualization, as will be described later. Many active learning activities can be used to design a AR-based curriculum. We called such activities Augmented Reality Active Learning (AnReAL). A theoretical framework that explains the advantages of using such a curriculum, which is based on the motion of the students, is provided by the emerging theory of embodied cognition [12][13][14][15], for which "knowledge is grounded in sensorimotor systems, and that learning can be facilitated to the extent that lessons can be mapped to these systems" [16]. It has to be noted here that embodied cognition is a very broad paradigm and that a narrower theoretical framework would be sufficient to be used to investigate the use of the presented device in physics education: we are referring to kinestethic learning, which was also at the base of the already cited ref. [1] and that also led to further important investigations [17].

2. Multiple-object, 6 DOF Tracking of Virtual Reality headsets

Let us start with some technical considerations. In the last few years, VR headsets have become increasingly accessible and user-friendly devices: with an average cost of a few hundred dollars/euros, we argue that they can be legitimate competitors of other educational instruments used for motion tracking. Also, the professional and free tools for software development and distribution are now more advanced than ever, and VR developing software libraries are generally given for free by the headsets sellers in order to encourage VR software development to their hardware.

The main VR feature which we are interested in is the one provided by the most common and advanced headsets available (such as Oculus Rift [18] and HTC Vive [19]), which is their innate capability of performing multiple-object, 6 degrees-of-freedom (DOF) tracking. In fact, the immersivity of VR is the result of the data about the rotation and position of the headset that are constantly gathered by the computer: by using these data, the computer is able to send the correct image to the VR displays so that the user can move freely and always be able to see the expected change in the image in front of her/him. The same principle holds true for the VR controllers, as they are always tracked as the headset.

There are two types of VR tracking systems: the first is based on external sensors which look for infrared signals emitted by both the headset and the controllers (the type we used), while the second is based on sensors which are built in the headset itself and that scan the environment in order to get the positional data, while also tracking the position and rotation of the controllers, again via infrared signals. Lastly, the frequency of these tracking systems needs to be sufficiently high in order to be effective: frequencies of 50 Hz are the bare minimum for such devices.

As a result, VR setups are effectively low-cost, high-precision, multiple-object, 6 DOF tracking systems that still need to be thoroughly explored for physics education activities about motion.

In what follows, we present our investigations based on simple custom software we developed in order to test this setup in an education environment, giving simple guidelines on how to reproduce such a software.

3. Addressing some possible concerns about the use of VR headsets in an educational context

We would like to start with what we think is an important consideration about the use of a VR headset in the laboratory or in the classroom. In fact, some teachers and students might feel uncomfortable with the idea of using VR headsets, fearing a sense of awkwardness or frightened by the risk of dizziness they think they might experience. Generally speaking, these problems are actually more linked to a low degree of proficiency with the actual media, or to poor experiences with past generations hardware. Let us not forget that these headsets are now being sold as entertainment devices addressed to the general public, and that there are simple design principles to be followed to develop a comfortable VR experience.

But more importantly than anything else, the reader has to be aware of this consideration: that everything that will be described in what follows do not require anyone to actually wear the VR headset. Of course, this might feel confusing, but VR setups are tracking and interacting devices, and everything that we are going to discuss here do not actually require the use of the headset. The reader can imagine this setup as a common sensor-based system plugged into a computer, visualizing the tracking data directly on the computer monitor. In fact, the image that the user sees while wearing the headset can be shown on the monitor. For these reasons, we believe that any concern of this kind about the use of a VR headset in an educational environment can be dismissed.

4. Passthrough experiences: from VR to AR

As it has been already mentioned, stereo cameras can be used to achieve Augmented Reality using a VR headset, as will be depicted in some pictures later. Intuitively, this technology is referred to as "passthrough", as the user is able to see through the headset by visualizing what each camera sees in the right spot inside the headset display.

By using this approach, we can mix a stereo image of the world in front of us with digital objects: the result is similar to what more expensive headsets natively achieve, such as the Microsoft Hololens [20], with some differences and some actual benefits. The general difference is that with the VR headsets are more immersive, meaning that they will completely block anything you can see apart from what is shown in the display, while the Hololens generally allow users to see everything around them while overlaying some digital information in a specific portion of the display. This is not inherently a win for either of the devices, it all comes down to the actual use that educators have in mind. Examples in the literature about use of the Hololens in the laboratory of physics can be found in Refs. [21, 22]. Both the Hololens and our setup allow projection on an external monitor or projector of what the user sees, which can be a very powerful feature in the laboratory of physics to allow students to work in small groups with a single headset.

Two general benefits of using our setup are the field of view (90° x 60° [23]), as this is still is the main Hololens technological limit (43° x 29° in the Hololens 2 [24]), and the cost difference (our setup costs 399$ for the ZED mini stereocamera plus the cost of a common VR headset, which is generally a few hundred dollars/euros, while the Hololens 2 costs 3500$). Another more specific benefit, which is the base of the processes we describe in this paper, is the automatic ability of the VR headsets to track the position of multiple objects, in particular the two controllers that come with the headsets (as well as other specific objects, called Vive "Trackers" [25] for the HTC Vive), as it will now be described.

5. Augmented Reality Active Learning (AnReAL) activities for exploring motion concepts

Examples of activities based on ultrasonic motion sensors include students making predictions about a certain type of motion, describing through words and/or graphs such predictions, performing motion measurements about the described motion (both walking in front of the sensor and using a simple motion cart) and commenting the results also taking into consideration their own predictions [1][2]. Cooperative learning is encouraged in these activities, for example by asking a student to describe to another student a type of movement the latter has to make in order to get a certain position/velocity/acceleration versus time graph.

On the other hand, as already mentioned, video analysis software proved to be a very useful tool for the laboratory of physics [3][4].

As will now be described, VR setup can be used in many different ways that can be of great interest for physics education laboratories, featuring many of the key positive aspects regarding both traditional systems (motion sensors and video tracking analysis) while overcoming many of their actual limitations. In particular, many active learning activities can be used to design a AR-based curriculum: we called such activities AnReAL activities.

5.1 The standalone-sensor setup

All the educational activities that can be done with the traditional ultrasonic sensors can also be performed using the described VR headsets, with many impressive advantages. The data about the position/rotation of the headset and controllers can be easily gathered using the free software libraries that come with the VR setup. These libraries can be used with software development tools (which also have options for free licences) such as Unity 3D or Unreal Engine. The basic software that can be developed simply plots position/velocity/acceleration versus time graphs using the acquired data in combination with common graph libraries. It is worth mentioning that it is not necessary for someone to *actually wear the headset*, only that someone or something moves the headset or a controller. The computer will record the position and rotation of the corresponding device and plot it on a computer display or on a projection. It has to be noted that the user can also choose to plot data regarding his/her distance from the sensors: in this very basic use of the setup, there is no difference for the users from the experience that they have when they use an ultrasonic sensor, apart from holding a controller *or* the headset with their hand. This is definitely not the best way of using the full capabilities, but this setup *can* replace ultrasonic sensors without implying any substantial change of the educational activities that have already been reported in literature about 1D motion.

From now on we will focus on what happens when the users wear the headsets. In figure 1 a screenshot of what a student can see while wearing the headset is shown: in particular, we can see the computer and the VR sensors in front of him, and the graphs about his distance, velocity and acceleration are superimposed on the image (if the student were not wearing the headset, but only carrying it by hand, the measurement could still be done and the image could still be seen on the computer monitor). Always (not only in this case) the data can be seen in real-time but also when the experiment is completed, and the resulting graphs can be seen both in the headset and on the computer display.

What we described is in all aspects a major upgrade from the experience that we can have with traditional motion sensors. Even leaving aside the AR part, which is of course the most interesting upgrade, we have a simple and cost-effective setup that is capable of doing a 6 DOF tracking. As already mentioned, this capability can be reduced to a 1 DOF tracking in order to replace the traditional motion sensors. Not only this, but as we already mentioned, we could track multiple objects at the same time (the headset and/or the 2 controllers.

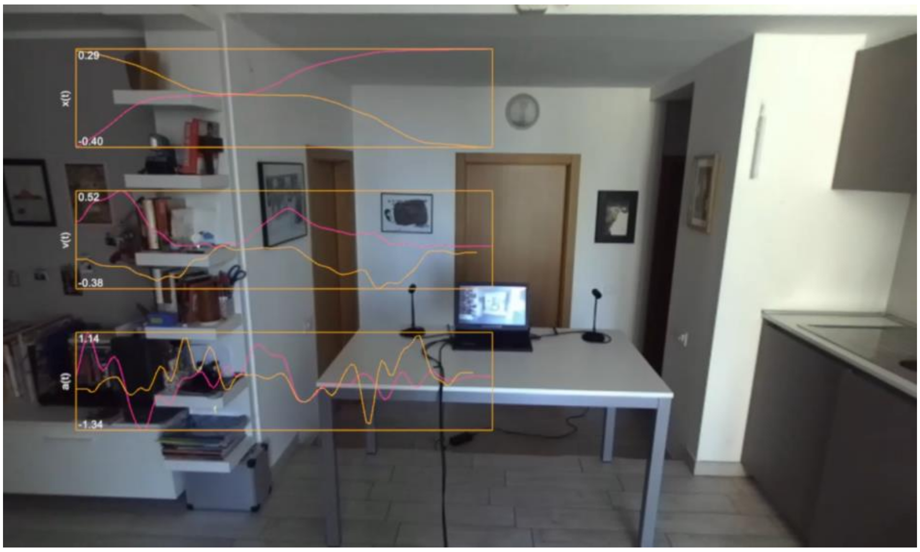

Figure 1. An example of what a student can see while wearing the headset. Here he is moving in front of the computer and the VR sensors, and he can see the graphs regarding his motion. The same data can be seen on the computer monitor, in real-time and also after the experiment.

5.2 Adding a 3D visualization of the tracking data

We will now discuss what can be achieved using a 3D virtual representation of the motion data, whether it will be seen inside the headset or on an external monitor.

With our software, it is possible to visualize a representation of the 3D data of the tracking of the headset and/or of the controllers: in figure 2, a series of spheres represents a small set of acquired positions. The student can move freely and visualise the tracking data in this way. Also, after measurements, the virtual representation of the data can be inspected moving freely around the 3D visualization.

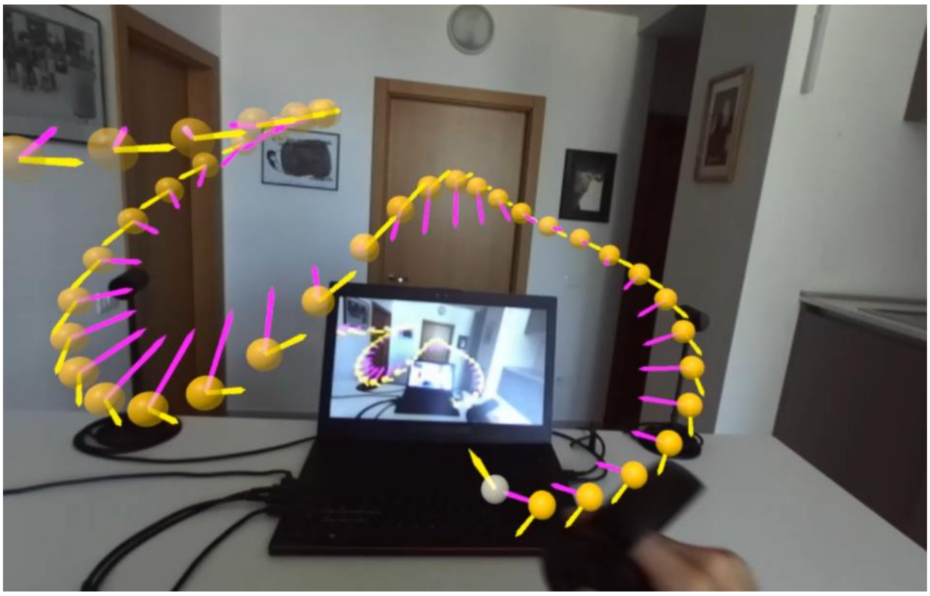

Figure 2. A 3D visualization of some of the acquired positions, here represented as colored spheres. Any additional physical quantity that can be derived from the positions can be visualized as well. Here, velocity vectors are displayed as yellow arrows, while acceleration vectors are visualized as magenta ones.

Any information that can be derived from the positions can also be visualised: for example, again in figure 2, we can see yellow arrows representing velocity vectors and magenta arrows representing acceleration vectors. Another example is given in figure 3, where a cyan arrow is represesnting the angular momentum. It has here to be noted that quantities such as the angular momentum, as in the case of angular velocity and angular acceleration, take full advantage of this 3D representation of the data. Even if an object motion lays on a 2D plane (e.g. a circular motion), those data cannot be generally visualized in a 2D environment, as they should be represented in an out-of-plane direction. This is a huge limit in video analysis techniques that are not addressed by any software known by the authors, while being automatically overcome by the AnReAL approach.

Another interesting feature to be noted is the capability of aquiring several data series while visualizing all the results together for comparison, as shown in figure 4: here, a visualization of three tracking series of a controller moved by hand at different velocities is displayed.

Figure 3. Vectors laying in the direction normal to the plane of motion are visualized naturally in the AnReAL environment. Here, an angular momentum vector is represented as a cyan arrow.

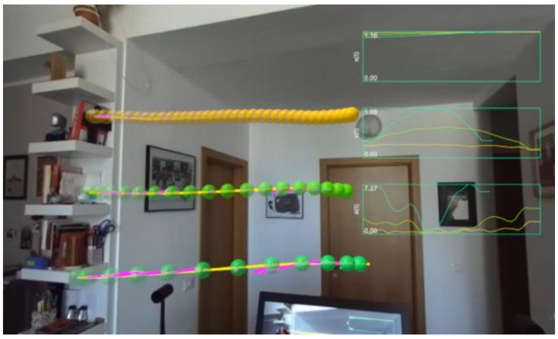

Figure 4. The system can acquire and display multiple data series for comparison.

The VR controllers can also be attached to some objects in order to track their motion. Also, as already mentioned, some companies sell simple devices that can be tracked by their setups (e.g. Vive "Trackers") and can be used for this purpose. In figure 5 it is shown the results of the tracking of a pendulum.

Last but not least is the capability of the AnReAL setup to perform the simultaneous tracking of multiple objects. In figure 6, we attached two controllers to a rotating platform, with different distances from its center of rotation, and the result of their tracking is displayed: in particular, we can clearly see the difference regarding the magnitude of the velocities and the accelerations of the two controllers, both by the differences of the corresponding vectors and also by the resulting graphs. As a last example of the tracking of multiple objects at the same time, we used two hovercraft toys (low-cost objects that can move with low friction in 2D) to study a 2D collision. As shown in figure 7, we attached a controller to each hovercraft, and their tracking is shown in the same figure. Here, we used a series of white spheres to also show the motion of the center of mass, and it can be seen that it is not visibly affected by the collision.

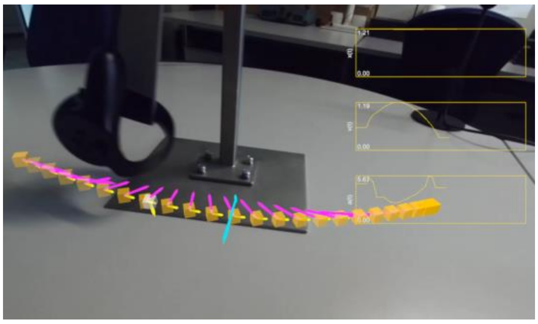

Figure 5. The tracking data of half an oscillation of a pendulum whose bob is the controller.

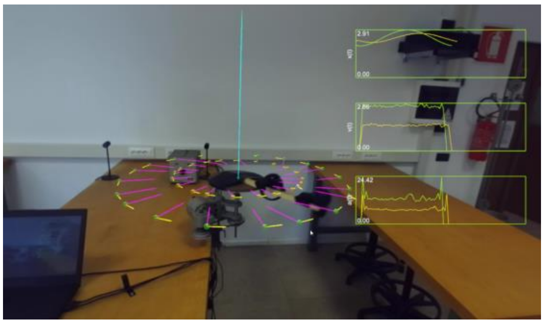

Figure 6. A visualization of the tracking data regarding multiple objects. Here two controllers were attached to a rotating platform at different distances from the center of the platform.

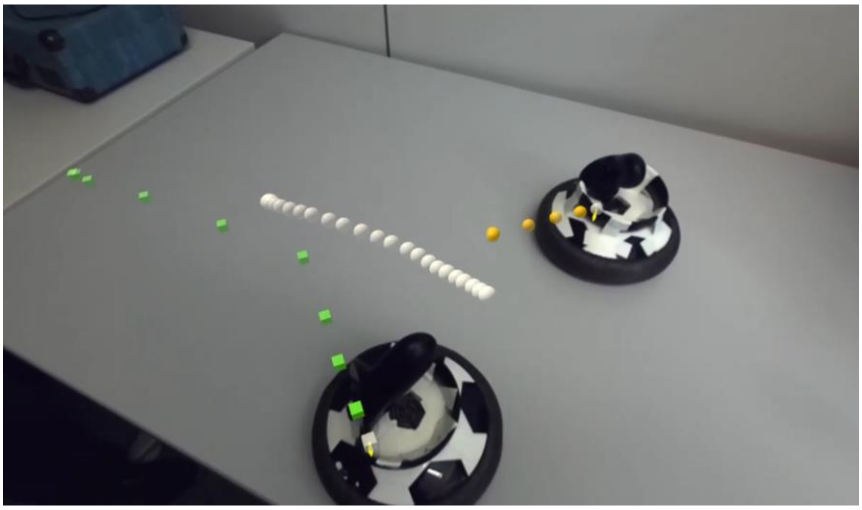

Figure 7. A collision between two hovercrafts: the center of mass of the ssystem is represented as a white sphere, which, as can be seen, is not visibly affected by the collision itself.

6. Preliminary testing with students

The setup has been tested during a course for master students of physics and mathematics regarding the teaching of physics at high school level. In the same course, they previously tried and commented on a modified version of the motion curriculum based on the traditional motion sensors as described in [1][2], and they have also used the Tracker video tracking software [3][4] in many experiments. The focus of this test was to gather their feedback about the comparison between the traditional activities based on the motion sensors or Tracker and of the AnReAL activities, and about the VR potentialities in general in a motion curriculum.

As expected, a couple of students felt a bit awkward at the idea of using a VR headset, and a few others were afraid of experiencing a headache as it is what they experienced at the cinema watching a 3D movie. While most of the students were actually very excited to the idea of using the headset, this kind of emotional response can occur in any classroom. We already addressed these concerns commenting how they would not affect the quality of the AnReAL activities.

In general, they particularly appreciated the simplicity of use of the setup. As they said, "it just works". This comment is particularly referred to some issues that it must be dealt with while using video analysis software: in fact, it takes some time to learn how it works and even then, it might pass quite some time between the experiment and the data analysis result. In this regard, the use of a VR tracking setup is similar to that of a motion sensor, as the user simply needs to start the tracking and perform the data acquisition, also receiving data in real-time.

At the same time, the motion sensor can be used only in a few kinds of activities, whereas the video analysis tool enabled them to analyse many different experiments. The students described this system as a good balance between the two traditional setups they have been using, being simple and fast to use as a motion sensor but also having a similar (actually, much larger in many ways) flexibility as Tracker.

Of course, we do not intend to present these comments as a structured evaluation of the effectiveness of the setup in an educational setting, nor do we propose to abandon motion sensors and video analysis activities. However, we find these preliminary results worth sharing, as starting from the comments coming from students that have been using all these tools for an extended time it might become easier to identify the areas in which they all excel and when to use one over the other. For example, the automatic 6 DOF tracking of specific objects of the AnReAL setup allows for a very intuitive, precise and real-time visualization of many physics phenomena, but of course it comes with the intrinsic limitation of the tracking of these objects, a limit that is not present in the use of Tracker, even though the latter is certainly limited in other areas compared to the former.

7. Conclusions

As we commented in this work, VR setups are low-cost, high-precision, 6 degrees-of-freedom, high speed, multiple-objects tracking devices. These setups prove to be very high-quality sensors that are well suited to be used in the physics laboratory for tracking in motion experiments. Augmented Reality can be achieved by attaching a stereo to the headset to allow students to see the 3D tracking of the experiment in the physical world.

A series of Augmented Reality Active Learning (AnReAL) possible activities have been presented, which can constitute the backbone of a motion curriculum to be thoroughly tested in the classroom. As commented by some students, the AnReAL setup features many of the positive key-points of traditional motion tracking tools, such as ultrasonic motion sensors and video tracking analysis software, while overcoming most of their limitations.

We also uploaded a video regarding the presented experiments in ref. [26].

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