Affordable Altered Perspectives

Making Augmented and Virtual Reality Technology Accessible

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***Abstract*—There is a lot of excitement about wearable computing, its applications, and its potential impact on the world. One ambitious prediction estimates that by the year 2018 the wearable computing market will be a multi-trillion dollar industry, with over 50 billion devices, more than half of which will be developed by companies that do not yet exist. One aspect of wearable computing involves the use of alternative interfaces, and the development of new virtual and augmented reality applications. Unfortunately, this is one of the most inaccessible technologies for all but the best-funded educational programs in the world, almost exclusively limited to the developed world. The reason for this lies in the expense of what is largely prototype display hardware, and the accompanying application development and experimentation tools.**

In this paper we describe our efforts to develop a low-cost platform that opens such application development to a much broader world, requiring the most minimal of hardware and computing infrastructure. We demonstrate how functionality that is typically limited to devices costing thousands of dollars, can be provided to students and educators with access to just a smartphone and under twenty dollars worth of materials.

I. Introduction

Wearable computing is rapidly becoming an exciting new market, and advancing well beyond the realm of science fiction speculation, and clumsy early prototype devices. This is in large part due to advances in technology that have rendered computing devices smaller, more energy-efficient, and thereby more practical to render wearable. As an example of the rapidly more ubiquitous nature of computing devices, the Institute of Electrical and Electronics Engineers (IEEE) recently highlighted this advance through the startling statistic that in the past seven years there has been a seventeen-fold increase in the number of internet-connected computing devices in the average US home [2]. For wearable technology, one recent prediction estimates that by the year 2018 the wearable computing market will be a multi-trillion dollar industry, with over 50 billion devices, more than half of which will be developed by companies that do not yet exist [3]. For such devices to interact more directly with the wearer, and to enable new applications of wearable computing, one exciting avenue of investigation is the use of wearable displays to augment, mediate, or replace the surroundings of the user. To that end, wearable devices such as Google's project Glass, and Epson's Moverio, are now within reach of developers looking to experiment with wearable displays. But this technology is well out of the reach of the vast majority of students in the world.

And yet, the very advances that have allowed wearable computing and augmented reality displays to become a reality, are the very same advances that could allow us to open up the opportunity for a greater number of students to experiment with such applications, and develop the future as-yet-to-be-invented applications of wearable computing. With increasing access to small, relatively inexpensive computing devices in the form of tablets and smart phones, more people have access to more advanced computing hardware than ever before. And yet, when it comes to wearable displays, they currently take the form of either expensive devices like Google Glass that connect to a smart phone, or virtual reality headsets like the Oculus Rift or the Sony Morpheus [11], which are not really intended to be portable and require connection to a computer or a console. There has been some departure from this, with a few amateur projects that attempt to use the smartphone display, and thereby the smartphone itself, as the primary computer and headset. But such projects (like that recently announced by Samsung, and various amateur projects to 3D-print a head mount for a smart-phone) are unavailable to those who do not have access to the facrication equipment and designs suitable for their specific smart phones, or who do not happen to use the specifically supported (typically top of the line) Samsung phone. All these factors mean that it is exceedingly difficult to use the increasingly ubiquitous smart phone and tablet devices as a means of making virtual reality and augmented reality technology more widely available to those who would wish to develop tomorrow's applications, but who do not have the adequate resources and funds to purchase the necessary hardware.

Our work has therefore been towards realizing a platform that can be cheaply constructed, and would be flexible enough to allow the use of portable computing devices of varying physical sizes. Specifically, we wished to develop a means of working with virtual and augmented reality, that could be inexpensively used with an array of smartphone or tablet devices. We have succeeded in developing such a prototype that costs no more than $12 to build, and which can be built with little more than the most basic tools and materials. Our prototype compensates for the primitve nature of its physical construction by depending on the software to render the necessary image on the phone or tablet display, and while far from the sophisticaation of the latest virtual and augmented reality displays, we have found it adequate for development and experimentation purposes. This opens the world of such development and experimentation to anyone posessing these basic materials, and a portable android or iOS device (such as an inexpensive android phone, an iPod touch, a nexus tablet, or an iPad mini).

II. Developing Wearable AR & VR Technology

Virtual reality systems allow a user to be immersed in a visual world that is generated by a computer. Augmented reality systems allow a user to see computer-generated data super-imposed upon the world around them. In traditional augmented reality systems, the goal is to enhance the observed world with additional information. Whether it is the ability to identify landmarks, or draw upon information displayed against the task at hand, the key feature is the enhancement and addition to our observed reality. A pioneer in this field, and inventor of many of the technologies that make such systems possible is Steve Mann, who has spent 35 years experimenting with virtual and augmented reality systems [4]–[6], [9]. He also illustrated the concept of mediated reality, wherein the natural view of the world could be improved upon, for example by replacing the view of a welding tool with the same view after it had been processed to improve (reduce) the contrast.

Unlike Radu *et al.* [7], our goal is not to evaluate the use of augmented and virtual reality in education, but to enable the education of as many students who wish to become proficient in virtual and augmented reality technologies as possible. We hope to afford a much larger group of students the tools necessary to realize the virtual and augmented reality applications of tomorrow, and thereby the opportunity to participate early in realizing the coming wearable computing wave. But we do not seek to do this using expensive hardware. Ideally, we would like students to be able to experiment with virtual reality, and augmented reality, using little more skill than is required to program a mobile phone application. We would further like whatever system we build to allow students to learn from the building process, to be able to replicate that process themselves easily, and to be able to adapt it to their specific mobile computing devices without resorting to the purchase or manufacture of custom parts of any kind. We believe we have achieved these goals with our latest prototype.

III. Initial Prototype

Our first experiments made use of the relatively inexpensive Oculus Rift virtual reality headset. This device was considerably less expensive than earlier virtual reality hardware, but was not really intended to be used in portable, augmented-reality applications. We got around its need to be attached to a computer and a power supply by integrating a portable lithium battery pack as its power source, and using a Google Nexus smart phone as both the computer driving this display, and as the camera mounted on the headset. The resulting system can be seen in use in Figure 1. While slightly unwieldy, it was completely portable and very usable as an augmented-reality system using open source computer vision and video libraries.

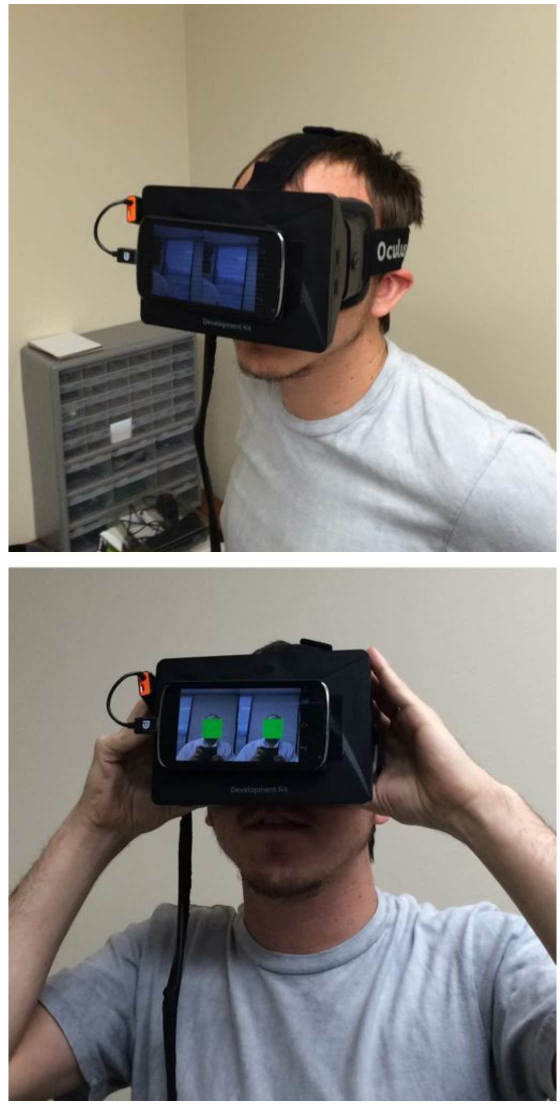


Fig. 1. Student with prototype based on the Occulus Rift headset. The hardware in this demo was suitable for both virtual and augmented reality development (thanks to the on-board phone's camera being used to supply the main video feed to the headset), but costs over $600, took several hours to assemble, and was generally unwieldy in use.

The downside of this approach is that, while *relatively* inexpensive, it cost almost $700 to implement.

In Figure 1, the phone's screen can be seen running an application the authors developed to perform live obfuscation of human faces. This was intended to demonstrate both the abilities of the prototype, as well as the potential of augmented reality technologies to illustrate serious arguments outside the technical and computing realms. By obfuscating human faces and figures, it is possible to demonstrate how such technologies can offer innovative solutions to arguments over, *e.g.*, imposed dress codes. For example, a person who claimed that they wished to impose a particular form of dress as a means of protecting modesty could be invited to apply such restrictions to their own eyes instead of another person's body. Demonstrating such points, and potentially changing the figurative perspective of people, is part of the appeal and potential for such technologies that literally change a person's perspective. Our goal is to make such demonstrations and experiments even more affordable and accessible to a broader audience, which demands an even more affordable approach.

IV. Current Prototype

Aside from the expense, a disadvantage of our initial, Oculus Rift-based, prototype is its potential redundancy (especially when a preview screen is not needed). It makes use of two displays. The first is the display within the headset itself, and used by the wearer as a means of observing the video feed (in this case, the view from the camera of the smart phone mounted on the headset itself). The second is the display in the smart phone, which is arguably unnecessary (although useful in a minor way for demonstration purposes, as it allows a second party, facing the wearer, to see the view being observed by the wearer). Eliminating this redundancy can clearly provide a savings if we were to use the smart phone as the primary display for the wearer. This approach would also eliminate any redundancy in the use of accelerometers and other sensors that are integrated into virtual reality headsets, but duplicate the abilities and hardware already integrated into a smartphone.

An alternative solution might have been to use a 3D-printed, or injection-molded, plastic holder for a smart phone, such as that proposed recently by a company called "seebright" [1]. The problem with such a solution is that it is once again more expensive than necessary, and results in a product that is too rigidly tied to a specific piece of hardware (the specific smart phone model it supports). In essence, these solutions attempt to offer a commercial product (as opposed to a flexible inexpensive development tool) and fail to offer a satisfactory product or the best path to an inexpensive implementation.

The prototype we have constructed is intended to demonstrate the extreme affordability that is possible. It is arguably more effective as a means of learning and experimenting with augmented reality applications than previous phone-specific "inexpensive" phone mounts [1], and is definitely more affordable than any earlier augmented or virtual reality display technology.

Our prototype was inspired by simple stereoscopic photograph viewers, and to construct it, we made use of the following materials (at a total cost that is approximately $12 in US currency):

- One 20"x30" foam board – $2.50
- One set of welding goggles with 50mm eyecups – $6
- One set of 50mm concave lenses with 10cm focal distances – $2.50
- Adhesive tape – $1

To build and assemble the prototype, we require no more than the following tools:

- A steel ruler
- An appropriate foam/cardboard cutting blade
- A marker pen/pencil

Figure 2 illustrates the stages of constructing our prototype, which we have tested with two different smart phones. We feel that in addition to the affordability and accessiblilty of our approach, the process of building such a simple viewer is in and of itself a valuable experience for a student.

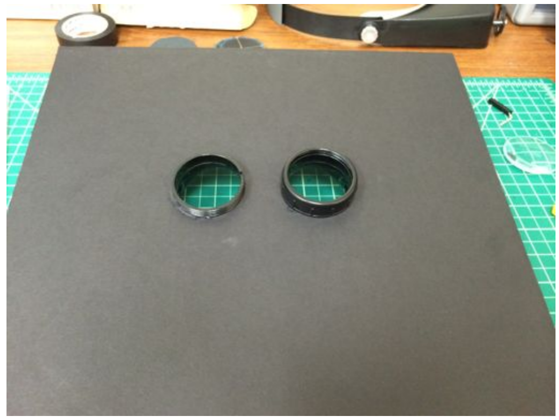
The prototype is built by starting with half of a piece of foam board. The kind we used was a 20 by 30 inch board, but could be replaced with a hard cardboard of similar size. The "welding goggle" used was an inexpensive pair, commonly available and was selected simply because it afforded an easy means of adding eye-cups and lens holders to the board. The goggles had a simple screw-on mechanism to hold the heavily tinted plain glass lenses that are normally used in cheap welding goggles. We unscrewed the eyecups, removed the plain glass, and perforated the board to allow the insertion of those eyecups without their screw-on collars. The glass lenses were swapped out for short focal-distance concave lenses, and the screw-on collars were then reattached to both fix the lenses and attach the eyecups to the board.

The board is then cut manually, and scored to allow for easy folding (the latter being an unnecessary step if using rigid card board in place of foam board). The idea was to create a plane that is at a short distance from the eyepiece, yet was large enough to hold whichever smart phone or small tablet was available to the user. The way in which the board was folded allowed for manual adjustment of the distance between the back of the board (the plane that is furthest from the eyepieces) and the eyepieces through which the user would look. Once the image on the screen was visible and in-focus, the distance to the eyepieces could be fixed by attaching the final free edges of the board with adhesive tape.

The above is the bulk of the construction effort of such a device. The idea behind it finds inspiration to stereoscopic photograph viewers, like those used for stereoscopy in the nineteenth century [10]. The resulting simple device is inadequate for use as a virtual or augmented reality device without the appropriate modifications to the image being observed. At a bare minimum this requires the separation of the image into two parallel images on the device screen. The exact placement of those images likely requires further callibration and adjustment, all of which is straightforward in software. Ideally, the two images should be binocular images drawn from two video sources, but in this simple prototype we used a split view of the single video feed being generated by a smart phone's camera. The additional hole in the "back" of the folded-board holder (see Figure 2), was to allow an unimpeded view by the rear camera of the phones we used. This last modification (the opening for the rear camera) is not strictly necessary for virtual reality application development, but is absolutely essential to allow for augmented reality applications.

The finished device, with an android smart phone mounted inside it, is shown in Figure 3 beside a Google Glass device

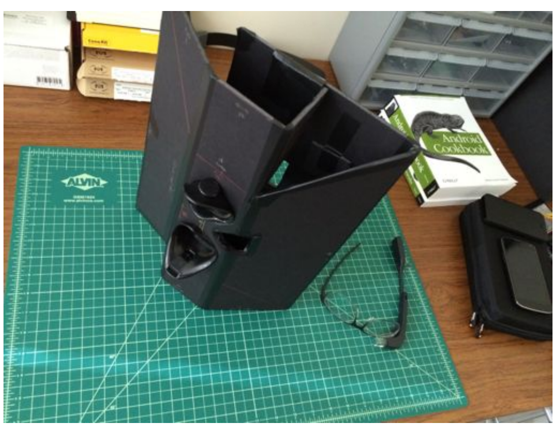
(a) Welding goggles and replacement clear concave lenses.



(b) Attaching goggles to foam board using the threaded lens frames.

(c) The foam board with goggles and lenses installed, and being prepared for cutting and scoring prior to folding and securing majority of the board's length.

(d) A side view of a completed device, this one prepared for a small screened device. In this instance, it was a large smartphone, but larger devices can be accomodated by adjusting the distance between the device and the eyepieces.



(e) An angled view of the device, showing more clearly how it is simply a folded portion of a foam board intended to hold an electronic screen at a fixed distance from the eyepieces.

(f) A view of the side opposite the eyepieces. In this instance, the backing was cut to accomodate the read camera of the phone being used.

Fig. 2. Construction process for a pair of DIY augmented/virtual reality goggles.

fitted with prescription lenses. The author did not need to use prescription lenses with the DIY goggles on the left, as they were manually adjusted to keep the phone screen in focus (which was a considerably cheaper and quicker procedure than the expense of having an optometrist prepare the necessary lenses for the custom frames needed to similarly adjust the Google Glass device). And yet, both devices, when paired with a smart phone, allowed the development of augmented reality applications. One interesting difference between the two devices is that the inexpensive prototype we built is actually capable of being used to test fully mediated reality applications such as those envisioned by Steve Mann for welding applications [6], wherein the device is used to obscure the harsh high-contrast view, and replace it with a more selectively darkened one. An augmented reality system intended to be worn more discreetly (as is the case with Glass) is useless in such an applications, but the simple DIY goggles we fortuitously built around eye cups taken from cheap welding goggles, could easily be used to demonstrate applications such as computer-augmented reality for a smart welding helmet.

A few months after this exposition of our work was submitted for review and publication, and as we were preparing final drafts of this document for the conference, Google engineers presented a similar project, dubbed ”Google Cardboard,” at the Google I/O conference [8]. Our design can be used with the software library provided in the independently developed, and truly impressive, Google Cardboard project, but there are some differences and caveats that we must note. Our own software efforts included experimentation with computer vision applications, but are otherwise less polished than the Google offering. However, our software was developed for both Android and iOS platforms, and our viewer design trades some precision in the dimensions in favor of considerably greater flexibility for manual adjustment and screen sizes. Specifically, the manner in which our viewer utilizes a folded (and adjustable) plane to serve as the mount for the phone/tablet allows the student to adjust the distance to accomodate the lenses that were available (we used 10cm focal length lenses, but increasing or decreasing the angle of the back plane before securing it allows us to adjust for variations in this distance). A disadvantage of this manually adjustable design is the inconvenience of experimenting to fine-tune the distance before completing the construction of the viewer and the need to perform more adjustments to the on-screen image than would be required with a fixed-length design. And yet a considerable advantage of this manual adjustment, in addition to the flexibility of lens choice, is the added flexibility of device screen sizes. Our viewer is usable with anything from a basic smartphone to a small tablet such as an iPad mini.

Fig. 3. The DIY goggles compared against Google’s Glass. Both require a smartphone, but the DIY goggles we constructed on the left were constructed in under an hour using less than $12 of simple materials. Google glass is a more capable and wearable device, but would cost a developer over $1,500 to purchase (placing such technology well outside the reach of most students, particularly in developing countries). The DIY version, while unwieldy, was found to be more convenenient for experimentation and less unwieldy than the earlier development prototype, which had been built around the Occulus Rift (and shown in Figure 1).

Student Experiences

Students were given the opporunity to use both the unmodified Occulus Rift headset, and both our prototypes. Their experiences were illuminating, particularly when they used the first prototype (*i.e.*, the more expensive version implemented by modifying the Occulus Rift and pairing it with a smart phone) and compared it to their experiences with traditional VR applications. When first switching from trying out Virtual Reality versions of computer games, and then switching to an augmented view of their surroundings, it was noted how the augmented version was a more comfortable experience. This was somewhat surprising, as the ”augmented” reality experiments were using the most basic software and offered an arguably much poorer viewing experience. In other words, the software and hardware were not tuned to offer anything close to an accurate viewing experience, and was yet a more pleasant experience than an immersive experience in a completely virtual world. The reason for this impression was quickly linked the most likely culprit - human ears and our sense of balance.

What the students had stumbled upon was a fundamental difference between virtual and augmented reality experiences. In the latter, the change in view is prompted by the actual physical movement of the observer. So even if the image is not perfect, the sensations of motion are almost perfectly matched to the view. Whereas in a pure virtual reality application, the sudden movements of the viewer in the virtual world are not typically matched to a sensation of such motion. All problems stemming from motion sickness and discomfort with the physical disconnect in a virtual reality experience are therefore largely absent in the augmented reality experience, as the students quickly noted when they described the experience of using our prototypes as ”more comfortable.”

V. Conclusions, Status, and Further Possibilities

In this paper we have briefly described how we constructed a simple build-it-yourself augmented/virtual reality platform that can be built around a smart phone or small tablet with minimal expense. For $12 in materials and some very basic simple tools it was possible to build our latest prototype.

The limitations of our system include the fact that it requires a fair amount of initial manual adjustment, and does not result in the best quality virtual or augmented reality experience. For example, we did not perform precise transforms on the split images to compensate for distortion due to the slightly off-center lens focal points. We found that the quality of the images was nonetheless surprisingly good, and the distortions were within the users' ability to compensate. A further limitation of our prototype is that it was only tested with the simplest of video processing and computer vision algorithms (basic shape detection), but more complex algorithms and transformations should be well within the capabilities of an ever larger proportion of mobile phones and tablets as computing performance increases. At the moment, such complex processing is feasible with most high-end to mid-end smart phones. As it becomes feasible for more devices, the practicality and range of experiments that can be conducted with our platform should also increase. However, our system is exceedingly inexpensive and arguably allows for a broader range of experiments than far more expensive hardware currently available.

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