"GlassEyes":

The Theory of EyeTap Digital Eye Glass

This paper is supplemental material for "Through the Glass, Lightly", IEEE Technology and Society, Vol. 31, No. 3, Fall 2012, pp. 10-14, and summarizes the "**Theory of Glass**" ("Theory of EyeTap Digital Eye Glass") also described in some detail in the textbook, "Intelligent Image Processing", Steve Mann, IEEE-Wiley Press, 2001.

"GlassEyes" Background: The Transparent Society

Putting sensors on people will create huge strides forward in health and wellness, for individuals who choose self-monitoring. For example, an individual can now transmit live streaming (or captured) ECG (electrocardiogram), together with live first-person video, to a physician who can see what the patient is doing, while examining the corresponding ECG waveforms. This can help to determine the root cause of heart-related problems and identify causes of stress in the patient's environment.

Veillance:

Consider, for example, a "black box" health recorder that captures information about a patient and the environment around the patient, much like the "black box" flight recorder of an aircraft. In the event of a physical assault, murder, or accidental death, such a device might help determine the cause of death. In less extreme examples, such a device might also help people improve the quality of their lives by helping them (and others they trust, such as their doctors or health advisers) understand the world around them.

Putting sensors on people raises important privacy and copyright issues in the realm of Technology and Society. For example, is a local capture of data for personal use considered a copy? When widely used as a vision aid, do we need to re-think Open versus Closed (or "Clopen" to use a portmanteau coined by Vardi [1]) access?

We already accept IoT. And we already accept cameras on things, i.e. **sur**veillance. Protecting human life is much more important than protecting merchandise, and putting cameras on people (this is known as **sous**veillance) is a natural and direct way of achieving human security [2][3] — putting people first — in a world that has previously been focused on the security of property (places and things). Thus we'll see a transition from surveillance to veillance, and a transition in sensing (not just for security but also for quality-of-life, and many other applications) from "things", to "persons, places, and things".

This Internet of People, Places, and Things, will create a more complete picture than merely the Internet of Things.

For example, putting cameras on people will give rise to a veillance-society rather than the surveillance-society arising from putting cameras only on property (places and things).

Surveillance is a French word that means "to watch from above". Police watch citizens. Corporations watch their customers.... But "veillance" (simply "to watch") means that sensing will occur in all directions, not just top-down.

This transformation in our society is being enabled by the miniaturization and mass-production of society. Cameras that were once big and heavy gave "intelligence" to land and buildings. Now they're small enough to give that "intelligence" to people. With the growing population of elderly, and as all of us age and our eyesight gets worse, we'll look to Digital Eye Glass to help us see better. Our eyeglass prescriptions will be adaptive, automatically updating and adapting to whatever activity we're engaged in.

Giving people the ability to see — is more important — AND LESS PRIVACY INVASIVE — than giving property the ability to see.

Many technical challenges remain, however, and we must focus on the specific challenges of sensor alignment, ruggedness, and portability (miniaturization), as well as psychophysical effects of long-term adaptation to mediated eyesight.

For example, a surveillance camera fixed on the ceiling does not need to withstand the same rigors as an eyeglass that sometimes falls off and hits the ground, or gets wet in a thunderstorm or when the wearer goes for a swim in the ocean.

And where surveillance cameras can be wired to the Internet, sousveillance cameras (eye glass) require wireless communications.

Lastly, and most importantly, when we wear something, it begins to funcion as part of us. Digital Eye Glass, for example, affects (modifies) how we see the world around us.

Even regular safety glasses, fitted without the attention to individual customization, can sometimes deleterious effects on balance and vision[4]. For example roof workers often don't wear safety glasses because the risk of falling off the roof may be worse than the eye injuries that might result.

But more importantly long-term effects of eyewear must also be considered. And we adapt to new and better ways of seeing the world, this adaptation can result in improved quality of life, but it can also result in brain damage and strange visual "flashback" effects as wearable computing has the possibility to "rewire" the brain, in a bad way, especially if the camera does not align exactly with the eye (i.e. if it does not meet the three "EyeTap criteria"[5]).

As this is a new technology, we do not yet have a huge sample population of users for long-term (many years) user-studies.

Wearable Computing:

Whereas AI (Artificial Intelligence) is an attempt at emulating human intelligence using computers [6], HI (Humanistic Intelligence) attempts to merge humans with computers so as to create intelligence from the human being in the feedback loop of a computational process [7].

During my childhood, back in the 1970s (when computers were usually massive machines that required large computer rooms) I was, as far as I know, one of only 2 children in our city (Hamilton, Ontario) to own a computer. It was one of the first "microcomputers". I attached it to myself as a prosthetic extension of my mind and body.

For more than 30 years, I lived my everyday life in a computer-mediated world. The pictures below document various stages of my "Augmediated Reality" work that ran from the 1970s to the present:

Steve Mann: Evolution of wearable computing in everyday life

1980 1995 passport 1999 2004 with firstborn child

In the 1970s and 1980s, people thought it was a crazy idea to have body-borne computer. But when I took these inventions and ideas to MIT in the early 1990s, to start a wearable computing project, people eventually began to see the merit in wearable computing through the 1990s. I've been recognized as "the father of wearable computing" (IEEE ISSCC 2000), and wearable computing is now said to be a $241 billion industry. But wearable computing is, by its very nature, an individual and personal praxistemology, deeply rooted in tinkering and critical sensemaking[1].

For an overview of wearable computing, see [8], [9], and `http://www.interaction-design.org/encyclopedia/wearable_computing.html`

A Theory of Glass:

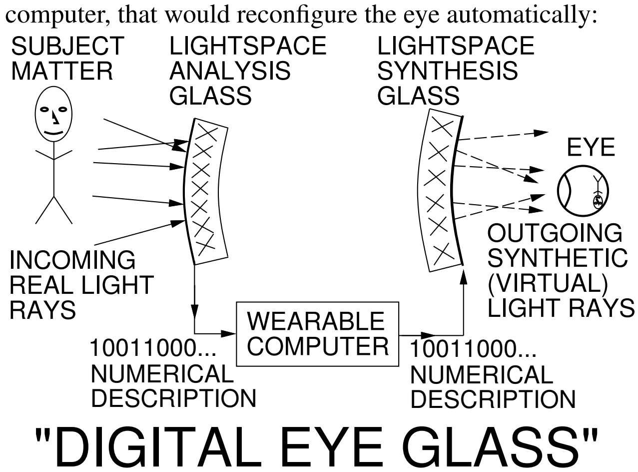
My explorations in wearable computing were directed toward a vision aid, and a mechanism for seeing and understanding the world better, through something I called "Augmediated Reality" (AR), as separate from the use of optical-only glass [10]. By this I mean that visual reality can be Mediated, Deliberately-Diminished, or Augmented, in order to see and understand the world better.

I learned to weld when I was 4 years old ("stick welding" back in those days, but I taught both my children how to TIG-weld by the time they turned four).

In my childhood, I envisioned a glass that would diminish/mediate the bright areas of an electric arc while augmenting the dark areas, thus "augmediating" my field-of-view. I became fascinated with welding glass, and began cutting out pieces of various shades of glass and joining them together to make an "augmediating" glass — the manually reconfigured eye.

Welding glass is well known [11][12][13], and apart from auto-darkening helmets like 3M's "Speedglas^{TM}" (everything goes dark when the arc starts), not much has changed in that world. Even with Speedglas (http://3m.com) "auto-darkening welding filter, a combination of liquid crystal elements, polarizers and electronics" (http://3m.com), once the arc is struck, the whole glass goes dark, and you can't see much other than the tip of the electrode's arc.

I formulated a theory-of-glass — a peripheral for the wearable computer, that would reconfigure the eye automatically:



Rays of eyeward-bound light strike a "Lightspace Analysis Glass" (which need not necessarily be flat, and is therefore depicted as being curved), are converted to numbers which may then be processed by the wearable computer. The resulting numbers are fed to a "Lightspace Synthesis Glass" to be converted back into light. This allows the wearable computer to become a visual intermediary, to, for example, diminish the bright areas of the Subject Matter, and

[1]For the history of the MIT wearable computing project, in Nicholas Negroponte (Director of the MIT Media Lab)'s own words, see `http://wearcam.org/nn.htm`

Augment/Mediate the bright areas, before resynthesizing the rays of light into the Eye, as shown in the above figure.

In what follows, I will explain the "Theory of Glass", originally motivated by the development of a seeing aid for welding. Together with other members of my family, I originally built various computerized welding helmets, as a commercial enterprise, as a small Mann family business. We produced a product known as the MannVis Glass^{TM}, MannGlas^{TM}, Digital Eye Glass^{TM}, GlassEyes^{TM}, or just Glass^{TM}, which we hope will eventually replace 3M's Speedglas^{TM} product that is now currently the "gold standard" in the welding industry.

Generation-1 Glass:

I built a rough approximation to this Glass in 1978, using a television camera as the "Lightspace Analysis Glass" a miniature glass cathod-ray tube as the "Lightspace Synthesis Glass" (over my right eye), and some electric circuits as the wearable computer.

Because the camera was located beside my eye the long-term effects after many hours of wearing the apparatus consisted of an adaptation to this strange way of seeing, and the adaptation persisted after removal of the apparatus.

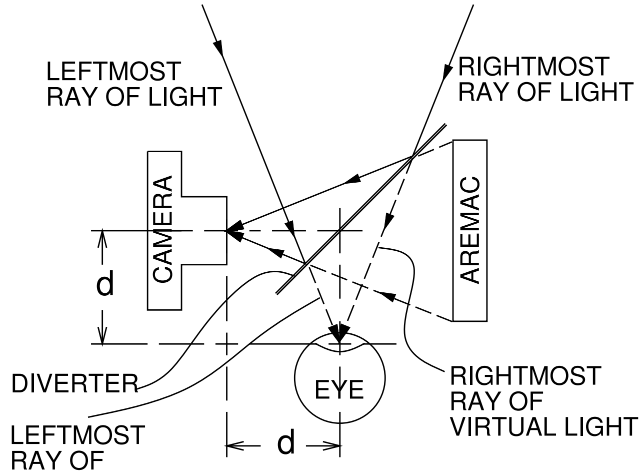
I'd read about George Stratton's work in 1896 with upside-down eyewear (done optically rather than electrically), but my electric eye glass allowed me to experiment with many different kinds of mappings.

I also observed that mappings that deviate moderately from what the unaided eye would see, were harder to "forget" than mappings that were either closer to or further from what the unaided eye saw. Thus I formulated a theory and practice that suggested one needs to either get the mapping perfect, or make it quite different from normal reality (e.g. present the image upside-down, or backwards, if one can't get close to reality).

Generation-2 Glass:

An eyeglass with a camera and display integrated into it, is what I refer to as a Generation-1 Glass.

Due to many of the long-term adverse effects encountered with Generation-1 Glass, I proceeded to invent Generation-2 Glass, which causes the eye itself to, in effect, become both the camera and the display:

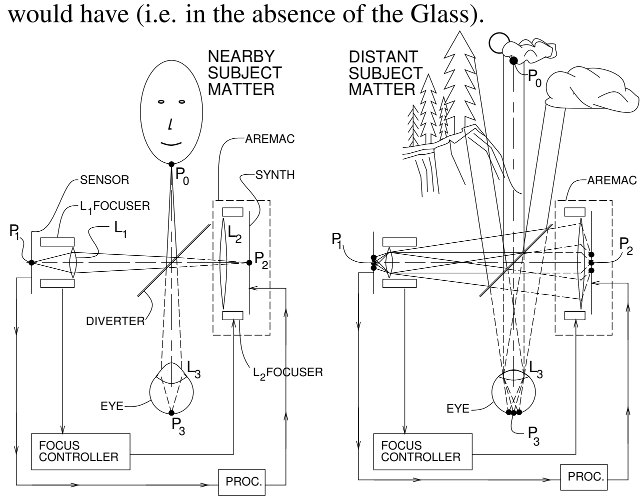


GENERATION–2 GLASS

Rays of eyeward-bound light are diverted into a Camera system that feeds to the Wearable Computer which then drives an Aremac (Lightspace Synthesis Glass). In this way rays of light that would have entered the unaided eye are collinear with rays of light presented by the Glass.

Generation-3 Glass:

Observing that the focus distance at which objects appear was a problem, I next created Generation-3 Glass which includes a focus control mechanism so that if one looks through the Glass the eye will focus to the same point as the unaided eye would have (i.e. in the absence of the Glass).

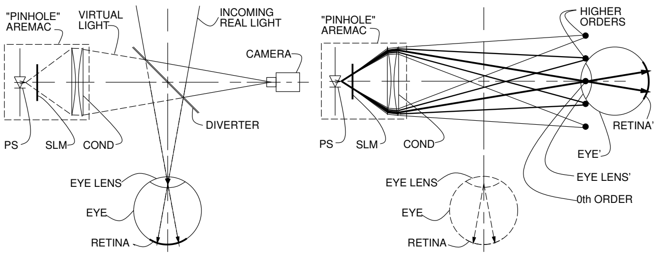


GENERATION–3 GLASS

Generation-4 Glass:

Finally, I noticed that, while looking at objects in various focal planes, such as looking at a distant object through a nearby screen or chainlink fence, some problems remained.

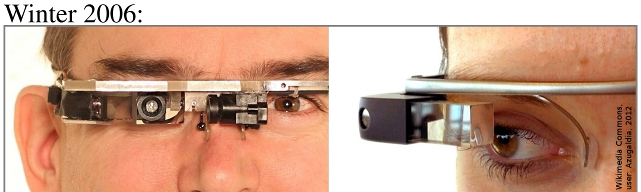
For this reason I created Generation-4 Glass using a laser light source with a spatial light modulator, and the like, to attain infinite depth-of-focus:



GENERATION-4 GLASS

Generations 2 to 4 of the Glass were known as "EyeTap Digital Eye Glass" [14] (the word "Glass" appears in singular form, not plural, i.e. "Eye Glass" not "Eye Glasses").

The result was a natural experience with zero eyestrain which I could wear continuously many hours a day for many years. The Generation-4 Glass was completed in 1999, described in detail in 2001 [5], and featured as the lead article (the cover, first page, and pages 31-32) of Abilities Magazine, Issue 69, Winter 2006:



Mann's 1999 "EyeTap Digital Eye Glass" 2012, Google Glass

Leftmost: Generation-4 Glass completed in 1999. The eye itself is the camera exactly! That is why the "Digital Eye Glass" is also known as the "GlassEye" (The eye looks exactly like a camera lens). This eliminates long-term dizziness, vertigo, and flashback effects that can otherwise persist long after the Glass is removed. Rightmost: Google Glass, 2012. The camera being to one side of the eye makes this a Generation-1 Glass. Long-term neurological issues, dizzziness, vertigo, and flashback effects, etc., can issues can result. from effectively moving the eye out of its eye socket and putting it off to one side.

Commercially made products such as Google's Glass bear a similarity to this EyeTap Glass (same slender aluminum strip, same two silicone-pads on the nose, similar glass over the right eye), but Google's Glass is a Generation-1 Glass (camera is to the right of the eye, not the eye itself as in Generations 2-4 of the Glass).

One important moral and ethical question: should Glass be mass-produced if it can potentially cause harm due to long-term adaptation, damage to visual cortex over time, etc.? Or should manufacturers provide a Generation-2 or higher Glass to avoid these problems?

A number of companies are making and selling Generation-1 Glass (glass that does not align the camera in a natural eye position, and therefore does not meet the important EyeTap criteria [5]):

space: spatial (collinearity) and spatial frequency alignment (orthoscopic and orthofocal);

time: orthotemporality [5] and temporal-frequency (non-lagging, etc.);

light: comparametric/superposimetic/orthoquantigraphic [7][5].

Such glass could have long-term adverse effects.

Going further: Generation-5 Glass:

In my days at Massachusetts Institute of Technology, I had the pleasure of working closely with Steven A. Benton, the inventor of white-light holography as well as the inventor of holographic video. I believe that holographic video capture and display holds the answer to what I call Generation-5 Glass. In this situation, every ray of light entering the front of the glass is captured and processed as to its direction of arrival and spatiality, so as to produce a completely holographic video experience, augmediated by the wearable computer.

Technical challenges and imperatives:

If Digital Eye Glass is something we're going to use to replace (and go beyond) traditional optical eyeglasses, it could become ubiquitious, and therefore, ultimately mass-produced and widely used. Such ubiquity would mandate solutions to many of the remaining technical problems.

When the Glass is used as a seeing aid, a person relying on it to see properly can be put at risk if its source of electrical energy runs down while it is in use. Therefore some kind of backup power will likely be desirable, as will warning systems. Moreover, upon sensing electric power is running low, the Glass should gradually weaken its "prescription" or other effects, so as not to cause an abrupt change in the wearer's way of seeing (or not seeing) properly.

Another issue is wireless communication. Whereas sensors in the environment around us (surveillance, and the like) are often fixed to property like buildings and land, these sensors can be connected by wires for both power and communications.

But it would be much more inconvenient for a person to need to be tethered to a wire. Therefore, wireless communications will be of much more importance to the Internet of People, than to the Internet of Things where it is perhaps more of a luxury rather than so much of a need.

Technology & Society:

The existential nature of Glass (i.e. the everyday use of it, as if part of the mind and body) brings it beyond the borders of a research lab, and out into the real world.

One interesting discovery was the reactions of persons engaged in surveillance. It turned out that peer acceptance was not so much the issue as acceptance by the authorities like security guards and facility owners — very people architecting and maintaining the “surveillance superhighway”. These persons, in particular, objected to Glass out of fear-of-cameras, even though the Glass originally did not record anything (images were merely processed and passed through to the output side of the Glass).

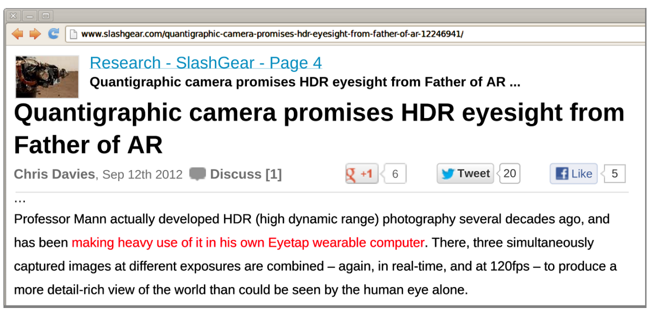
What seemed ironic was that the same persons conducting surveillance were the ones most opposed to something that seemed like the reciprocal of surveillance.

I became fascinated with the otherwise hidden sociopolitical machinery that became very evident to me, as viewed through Glass, but that nobody else could see.

Sur/Sousveillance:

The word “surveillance” is French for “to watch from above”. The closest English word is the word “oversight”. The logical reciprocal is “sousveillance” and “undersight”, to describe “watching from below” (from the French word “sous” which means “from below”). There are now hundreds or thousands of books, papers, conferences, and projects on sousveillance.

In addition to publishing this work in scholarly research journals, it also often appears in the mainstream media, because it has a direct affect on society:


www.slashgear.com/quantigraphic-camera-promises-hdr-eyesight-from-father-of-ar-12246941/

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Quantigraphic camera promises HDR eyesight from Father of AR ...

Quantigraphic camera promises HDR eyesight from Father of AR

Chris Davies, Sep 12th 2012 Discuss [1] +1 6 Tweet 20 Like 5

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Professor Mann actually developed HDR (high dynamic range) photography several decades ago, and has been making heavy use of it in his own Eyetap wearable computer. There, three simultaneously captured images at different exposures are combined – again, in real-time, and at 120fps – to produce a more detail-rich view of the world than could be seen by the human eye alone.

Until recently most people had not cared much about this work, or how it might shape society. But recently (in the last 12 years), many people now use smartphones for AR, or simply to help failing eyesight by photographing and magnifying something, or perhaps to translate a foreign restaurant menu into their own language using an optical character recognition app. ... Penny Sheldon, a travel agent from Boise, Id., was physically assaulted by McDonalds staff in Paris, France, because she photographed their menu.

My uniquely personal experiences over the last 30 years are taking on new relevance as Augmented/Augmediated Reality goes mainstream. We are at a pivotal era where **the questions I am asking have become significant to society, and require answers!**

Forbidden QR codes:

Consider this group of pictures I recently took:

Many businesses prohibit cameras and cell phones, but at the same time require them to scan their QR codes, etc.
Photos by Steve Mann 2008-2011, from http://www.interaction-design.org/encyclopedia/wearable_computing.html

Here the signage on a box of watermelons advises shoppers to use their smartphones to see a sales pitch on the product to help them make a purchase decision. But many retail establishments also say “NO CELL PHONE IN STORE” and “NO CAMERAS/VIDEO”. So participants are **simultaneously required to use a camera, and forbidden from doing so**, in order to see this content. And customers are frequently harrassed by store security staff when all they’re doing is trying to experience a little bit of Augmediated Reality.

Whereas Glass helps people see better, without *necessarily* recording video, I’ve also been working on other cameras that do the opposite: lifelong video recording without *necessarily* trying to help people see better:


Wearable Wireless Webcam 1998, Mann | SenseCam 2004, Microsoft | Lifelogging Camera 2012, Memoto

This originally took the form of a camera necklace that mimics the appearance of the typical surveillance domes, yet is instead a fully functional Wearable Wireless Webcam for lifeglogging (lifelong cyborglogging), also known as lifelogging, moblogging (mobile logging), or the like. In 1998 I built a series of neckworn domes, some with built-in augmented reality and gesture recognition[15].

IEEE ISTAS 2013:

The theme of the IEEE International Symposium on Technology and Society (ISTAS) 2013, June 27-29th, in Toronto, for which I am the General Chair, is veillance (the

Internet of Things AND People). See
`http://veillance.me/`

Conclusions:

Generation 4 or 5 Digital Eye Glass will soon greatly improve our lives. By causing the eye itself to become, in effect, both a camera and display, when coupled with wearable computing, it will facilitate Augmediated Reality (AR) in everyday life. As a seeing aid, visual memory aid, personal safety device, and sensory integration aid, EyeGlass will likely replace optical eyeglasses.

But it also raises many moral and ethical questions that range from affects on the wearer (e.g. re-configuration of the brain's visual percpetual system through long-term adaptation), to affects on society in general (e.g. lifelong video capture, continuity-of-evidence, and the like).

These issues require our immediate attention, and that is why the IEEE is hosting the International Conference on Technology and Society on this very topic in June of 2013 (paper submissions due January 31, 2013)! See http://veillance.me

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