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Abstract

The Visual Assistant image-enhancement system is built around the idea that the presentation of the outside world should be tailored to the working parts of the visual system of the visually impaired user by enhancing the image to make the most of the residual vision they have. It enables people suffering from vision loss to modify every aspect of a TV image to alleviate their specific eye condition and enables them to see images more clearly.

By magnifying subtle visual information around the contours of objects we are able to uncover unseen clues about shapes and expose hidden edges, enriching the image and making it easier to be understood by the visually impaired user. A medical diagnosis of a person's visual impairment is used to design a degradation model able to answer a simple question: what is wrong with the image, and what can we do about it. As images on the screen are degraded by a well-understood process it can usually be reconstructed by reverse-engineering the degradation model. A reconstructive compensation strategy is modelled to counter the deterioration in a resolution of details, contrast or saturation. Based on the model a reconstructive adaptation strategy is created to counter the impairment of the eye lens and retina.

Introduction

Understanding the world visually begins with object boundaries. By enhancing the edges of an object we aid the viewer's cognitive process. Humans make sense of the world visually by understanding where one object ends and another begins – object edges are the most important feature for viewers attempting to make out small details. Enhancing at least some of the visual cues helps the human vision system to create a more accurate primal sketch.

The estimated number of people visually impaired in the world is 440 million [1] 216 million had moderate to severe visual, 188 million had mild visual impairment and 36 million are blind. Functional presbyopia affected an estimated 1094 million with 666·million being aged 50 years or older. Globally, the principal causes of visual impairment are uncorrected refractive errors and cataracts, 43% and 33 % respectively. Other causes are glaucoma, 2%, age related macular degeneration, diabetic retinopathy, trachoma and corneal opacities, all about 1%.

Our eyes exhibit age-related changes in performance as we age — particularly as we reach our 60’s and beyond. Lens muscles that control our pupils lose some strength. Cells in the retina that are responsible for normal colour vision decline in sensitivity as we age, causing colours to become less bright and the contrast between different colours to be less noticeable. 8 out of 10 people over the age of 65 suffer from some form of sight loss. A 2018 survey commissioned by the American Foundation for the Blind in partnership with Comcast shows us that visually impaired people watch four or more hours per day — almost as much as the general public. 53% of those surveyed reported that they experienced difficulty in following along with key visual elements. We concluded from this survey and our own subsequent user testing that the majority of visually impaired people are digitally excluded from the full enjoyment of what the TV represents in the 21st century - a central information and entertainment hub.

Partial sight, ageing and congenital deficits all produce changes in perception that reduce the ability to distinguish shape-related clues. These changes influence accurate object recognition resulting in a decreased understanding of the environment. Experiments have shown that visually impaired people are more likely to recognise objects and structures in the environment if the boundary between objects of interest and the background around the edges of objects are clearly marked.

Picture 1: Different conditions that can be mitigated with Visual Assistant technology

Our Work

Media regulators have in recent years demanded that broadcasters and other providers make their content accessible through assistive technologies such as video description, text-to-speech and voice control for navigating on-screen TV programme guides. Visual Assistant technology takes accessibility to another level – the provision of moving images tailored to the specific eye condition of the TV viewer.

Enhancement of subtle changes in the displayed image adds back a sense of reality and brings an improved sense of the physical to the visually impaired. By enriching natural visual cues with artificial elements users can heighten their contrast sensitivity and visual acuity greatly. A better understanding of the fundamental perception components of salient objects in the world ultimately leads to a visually impaired user’s ability to decipher the shapes of objects, enabling easier comprehension of dispersed and non-continuous visual information [2]. We have discovered that even a minimal enhancement of image visual cues has a profound impact on our ability to decipher the content. Much research in this field has been focused on methods for superimposing high contrast edges over the existing image to increase 'readability' or 'viewability' by heightening the contrast between objects and background almost to the extreme. Augmented vision models have been proposed utilising visual multiplexing techniques such as the wideband enhancement algorithm that superimposed modified image edges over the original image, enhancing the high spatial frequency components],[4],[5],[6]. These methods all suffer from the paradox that they increase visibility by enhancing the contrast of high frequency, that is edge areas, but in doing so they decrease the quality and resolution of the image as a whole. The effect is further amplified by the visual cortex induced enhancement of edge bands beyond their true natural appearance. The result of these known techniques are unrealistic images.

Creating an inclusive digital TV experience for all has been at the heart of our R&D at Visual Assistant and the outcome of our work is a prototype Visual Assistant TV that enables people suffering from vision loss to modify every aspect of a TV image to alleviate their specific eye condition enabling them to see the images more clearly.

The Visual Assistant image-enhancement system is built around the idea that the presentation of the outside world should be tailored to the working parts of the visual system of the visually impaired user by enhancing the image to make the most of the residual vision they have. It enables people suffering from vision loss to modify every aspect of a TV image to alleviate their specific eye condition and enables them to see images more clearly. The human visual system makes decisions based on the presence of spatial distribution and intensity of depth and focus cues. The degraded image produces changes in perception that reduce the ability to distinguish details and greatly influence our ability to focus resulting in a seemingly blurred image. By changing the appearance of visual cues we can help our visual system to better process each image.

By magnifying subtle visual information around the contours of objects we are able to uncover unseen clues about shapes and expose hidden edges, enriching the image and making it easier to be understood by the visually impaired user. A medical diagnosis of a person's visual impairment is used to design a degradation model able to answer a simple question: what is wrong with the image, and what can we do about it. As images on the screen are degraded by a well-understood process it can usually be reconstructed by reverse-engineering the degradation model. A reconstructive compensation strategy is modelled to counter the deterioration in a resolution of details, contrast or saturation. Based on the model a reconstructive adaptation strategy is created to counter the impairment of the eye lens and retina.

The adaptation strategy based on a degradation model enables better 'readability' by enhancing and augmenting the most important visual cues. This produces graphic images that have enhanced colours, contrast, brightness and sharpness of details - changed according to the user's low vision or visual impairment functional needs. The aim is to emphasise the details of a scene so as to make them more visible to the viewer while changing the original image minimally.

Simulated visual cues can be perceived as unnatural when changes in intensity, contrast or pattern appear to be in stark contrast to adjacent areas. We discovered that together with changing the contrast in the depth cues, the spatial density of artificial depth cues needs to be influenced as well - this because our human visual system perceives any changes as unnatural. When spatial density is lowered to a suitable level and fused with the original image the viewer gets a realistic representation of depth cues that help trigger the correct accommodation as well as regenerating the natural feel of depth cues.

Using an alternative presentation for sharp edges by rendering them as sparse pixels allows us to represent a wider range of edges from the visually dominant to very discrete edges with minimal variations in the area. The most important part of the enhancement strategy is rendering the enhanced areas using a sparse pixel cloud method so that changes are accepted by the human visual system as natural shadow like structures. Densities of tiny halftone dots influence how the retinal image will be created gaining the influence of some reflex actions of the human visual system. Using an alternative representation for edges, by rendering them as sparse pixels, provides an opportunity to represent a wider range of visual cues from the visually dominant to very discrete ones even with minimal variability in pixel intensity values of the edge area. A non-deterministic process simulates natural light dissipation by an exponential degradation function that creates an increasingly random scattering of pixels to spread residual brightness information to the neighbouring pixels.

Although Visual Assistant offers out of the box prescriptions for most common vision impairments we know that every eye is unique. Every prescription can be further tailored and perfected to fit your eye condition. The prescription is a series of image modifications that restores the deteriorated areas of the retinal image by adding missing visual cues. The restored image is projected to the retina and perceived by the remaining vision with the best possible contrast, sharpness of details and vibrancy of colours.

Visual Acuity Loss

Visual acuity commonly refers to the clarity of vision and loss of visual acuity in portions of an image with fine detail (known as high spatial frequency loss). To resolve the loss of fine detail the eye's optical system has to project a focused image on the fovea, a region inside the macula having the highest density of cone photoreceptor cells, thus providing the highest resolution and best colour vision.

Picture 2: Right image shows a simulation of what the patient will see after we enhance acutance of image

An adaptation command chain strategy is based on augmentation of high frequency areas, contrast in these portions of the image with fine details are increased to highlight the differences in the detail by selectively brightening and darkening the edges of the detail in the image. People with refractive errors are not candidates for this kind of technology.

Contrast sensitivity loss

Sight is a contrast dependent sense and the real world is made of subtle changes in contrast. Loss of contrast sensitivity refers to an inability to distinguish between gradations of brightness or between shades that are similar in colour. Loss of contrast is often a good predictor of how extensive functional vision loss is. With some patients' loss of contrast further darkens the dark parts of an image while others feel that loss of contrast causes images to become greyer overall, to the point that edges can become lost.

Picture 3: Right image shows a simulation of what the patient will see after we enhance contrasts of details

Picture 4: Right image shows a simulation of what the patient will see after we enhance both acutance, contrast and colours of the image

One of several strategies how Visual Assistant overcomes contrast sensitivity loss is based on tonal remapping followed by a contrast remapping in dark, mid-tone and highlight areas. Linear tonal remapping improves the brightness mapping, spreading it uniformly across the dynamic range of the image, whereas nonlinear contrast remapping improves the brightness differences of the shadow and mid-tone, the darker regions, and/or highlight the brighter regions at the expense of the brightness differences in other regions.

Central field loss

Macular degeneration (Hole) is the leading cause of vision loss among older people. Macular degeneration affects the part of the eye responsible for sharp, detailed central vision. In practice, the eye naturally focuses on the centre of its vision. This makes it very difficult to look at things outside of the grey area. It can cause blurring or darkness in the centre of the visual field, and can also affect the ability to determine details and contrast.

Picture 5: Right image shows a simulation how patient with central field loss can modify image based on position and magnitude of the scotoma

An Visual Assistant overcomes blind spots first by determining their position and magnitude. Information on the position of the blind spot (scotoma) is remapped onto the relatively intact areas of the retina, parts not affected by the blind spot, by selective magnification and remapping of key areas of the image and shrinking the peripheral areas. The retinal area to which a specific element of the image is projected is increased, which increases the probability that more intact photoreceptors will be covered.

Peripheral field loss

Individuals with peripheral vision loss, so called tunnel vision, retain clear central vision. In some cases, small patches of retinal activity on the periphery are preserved, making it possible to detect movement and objects that assist with one's orientation. Visual Assistant overcomes tunnel vision by pushing some information from the edges of the visual field towards the centre of the retina where the visual acuity of Glaucoma, Retinitis pigmentosa, Detached retina, Optic Neuritis and Papilloedema patients is still working.

Picture 6: Right image shows a simulation how patient with peripheral vision loss can modify image based on the magnitude of the tunnel

Visual Assistant TV

Visual Assistant TV was designed by Visual Assistant Ltd in collaboration with the Computer Graphics Laboratory team at the University of Ljubljana. Visual Assistant has been presented and well received at Optometry forums in Rome, Athens and Klagenfurt. Our approach to the Royal National Institute of Blind People resulted in their asking for user testing that we conducted using an RNIB protocol. The Slovenian Association for the Blind and Visually Impaired agreed to help organise nationwide testing of our prototype that subsequently took place in 10 different locations. Invitations went out to potential candidates and 93 people offered to take part. Of the 53 **visually impaired** participants 43 (**78%**) participants performed the tasks better with the Visual Assistant TV and only 1 (2%) performed better without. A further 5 (9%) performed the same with or without the Visual Assistant

Visual Assistant is the first personalised video correction technology allowing you to create a TV experience aligned with your vision needs. Our system helps almost all visually impaired people with severe impairments or mild refractive errors to see images in more detail and contrast while also sitting further away from the screen. Every imaginable aspect of the image, from colour vibrancy, contrast of visual cues, sharpness of detail, brilliance of light (to mention just a few!) can be enhanced to create the best possible viewing experience.

Possible next steps

Low vision people would welcome a TV program to have higher acutance, enhanced contrast and more natural looking colours. The image quality issues inherent with streaming video persist and the demand to improve the quality of streaming video can only increase in the future. Visual Assistant is perfectly adopted to be embedded into new digital set top boxes to give them contrasting and sharpening abilities for the benefit of visually impaired. Broadcasters and streaming video providers such as Amazon, Netflix and YouTube will be able to complement their services with this technology to make video content on home entertainment systems more accessible.

Public service broadcasters are mandated to support content that caters to minorities and a primary broadcasting mission that speaks to and engages with its citizens whether sighted or visually impaired. They are natural partners for Visual Assistant technology. With an estimated customer base of 440m people worldwide we see Visual Assistant technology evolving from a dedicated set-top-box to an embedded chip within TV receivers.

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