Title

Towards Immersive Virtual Reality Simulations of Bionic Vision

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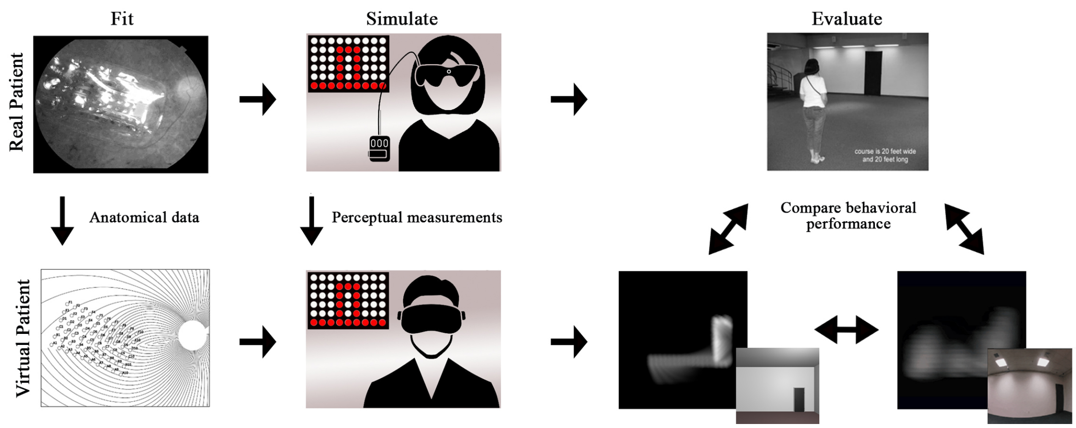

Figure 1: Virtual and real patients for bionic vision. *Top row:* Retinal prosthesis patient. A microelectrode array is implanted in the eye to stimulate the retina *(left)*. Light captured by an external camera is transformed into electrical pulses delivered to the retina to evoke visual percepts (*middle*), which a patient uses to walk towards a door (*right*). *Bottom row:* Virtual patient. Anatomical data is used to place a simulated implant on a simulated retina (*left*). Visual input from a virtual reality (VR) device is used to generate realistic predictions of simulated prosthetic vision (SPV, *middle*), which a virtual patient uses to walk to a simulated door in VR *(inner-right)*, or a door in the real world captured by the head-mounted display's camera *(outer-right)*. Edges stand out due to the specific preprocessing methods used, but a variety of methods can be tested. Behavioral performance can then be compared between real prosthesis patients, SPV of the real world, and SPV of the virtual world.

ABSTRACT

Bionic vision is a rapidly advancing field aimed at developing visual neuroprostheses ('bionic eyes') to restore useful vision to people who are blind. However, a major outstanding challenge is predicting what people 'see' when they use their devices. The limited field of view of current devices necessitates head movements to scan the scene, which is difficult to simulate on a computer screen. In addition, many computational models of bionic vision lack biological realism. To address these challenges, we propose to embed biologically realistic models of simulated prosthetic vision (SPV) in immersive virtual reality (VR) so that sighted subjects can act as 'virtual patients' in real-world tasks.

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CCS CONCEPTS

• **Human-centered computing** → **Accessibility technologies**; **Virtual reality**; **HCI design and evaluation methods**.

KEYWORDS

retinal implant, visually impaired, virtual reality, immersion, simulated prosthetic vision, vision augmentation, virtual patient

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1 INTRODUCTION

Retinal degenerative diseases cause profound visual impairment in more than 10 million people worldwide, and retinal prostheses ('bionic eyes') are being developed to restore vision to these individuals. Analogous to a cochlear implant, these devices convert video from a head-mounted camera into electrical pulses used to stimulate retinal neurons, which the brain interprets as visual percepts ('phosphenes'; Fig. 1, *top row*). Current devices have been shown to enable basic orientation & mobility tasks [1], but a growing body of evidence suggests that the vision restored by these devices differs substantially from normal sight [4, 10].

A major outstanding challenge is predicting what people 'see' when they use their devices. Studies of simulated prosthetic vision (SPV) often simplify phosphenes into small independent light sources [5, 8, 14] even though recent evidence suggests phosphenes vary drastically across subjects and electrodes [3, 10]. Another challenge is addressing the narrow field of view (FOV) found in most devices (but see [11]). This requires patients to scan the environment with head movements while trying to piece together the information [10], but many previous SPV studies are performed on computer monitors. While some studies attempt to address this [5, 8, 14], most fail to account for phosphene distortions. It is therefore unclear how the findings of common SPV studies would translate to real retinal prosthesis patients.

2 PROTOTYPE

To address these challenges, we embedded a biologically realistic model of SPV [2, 3] in immersive virtual reality (VR) using the Unity development platform, allowing sighted subjects to act as virtual patients in real-world tasks (see Fig. 1, *bottom row*). In this setup, the visual input about to be rendered to an HTC VIVE head-mounted display (HMD) mimics the external camera of a retinal implant. This input can come from the HMD's camera or can be simulated in a virtual environment. A combination of compute and fragment shaders is used to simulate how this input is likely perceived by a real patient. Unlike previous models, our work is based on open-source code described in [4], which generates a realistic prediction of SPV that matches the field of view and distortions of real devices. This allows sighted subjects to 'see' through the eyes of a retinal prosthesis patient, taking into account their head and (in future work) eye movements as they explore an immersive virtual environment. Future SPV models can be plugged in and applied to new prostheses once they become available.

3 RESEARCH GOALS

3.1 Provide realistic estimates of current bionic eye technologies

The prevailing approach to SPV is to assume that activating a grid of electrodes leads to the percept of a grid of luminous dots, the brightness of which scales linearly with stimulus amplitude [5, 8, 14]. By ignoring percept distortions [3, 10], performance predictions of such studies can be highly misleading. In contrast, our work is constrained by neuroanatomical and psychophysical data.

In addition, current devices are typically evaluated on simple behavioral tasks, such as letter/object recognition [7, 9], following a line painted on the ground, or finding a door in an empty room [13]. Even simple letter recognition tasks require head movements to scan the scene, which is best emulated in an immersive VR environment (note that $\text{FOV}_{\text{bionic eye}} << \text{FOV}_{\text{HMD}}$).

3.2 Assess the potential of advanced stimulation strategies

With the limited number of pixels found in current devices (e.g., Argus II: 6×10 electrodes), it is impossible to accurately represent a scene without preprocessing. Rather than aiming to restore "natural vision", there is potential merit in borrowing computer vision algorithms as preprocessing techniques to maximize the usefulness of bionic vision. Edge enhancement and contrast maximization are already routinely used in current retinal implants, and more advanced techniques based on object segmentation or visual saliency might further improve visual performance [12]. For example, using an object detection algorithm for cars could help prostheses users at a crosswalk (Fig. 2), while facial recognition or text magnification would be useful in other scenarios.

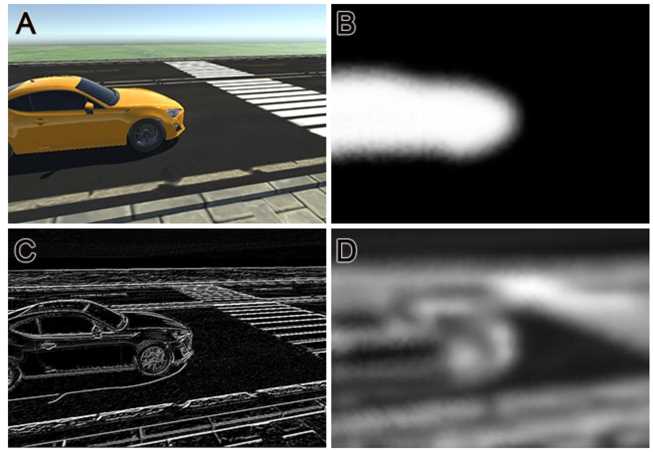

Figure 2: Different image processing techniques for simulated prosthetic vision (SPV). *A)* Original Image. *B)* SPV after segmenting important objects. *C)* Edge enhancement of the original image. *D)* SPV of the edge-enhanced image.

Although current bionic eyes have been implanted in over 500 patients worldwide, experimentation with improved stimulation protocols remains challenging and expensive. Virtual patients can offer an affordable alternative for designing high-throughput experiments that can test theoretical predictions, the best of which can then be validated in real prosthesis patients.

3.3 Guide the prototyping of future devices

The insights gained through virtual patients may help drive the changes for future devices. Obvious improvements could be realized by testing different electrode layouts and stimulation frequencies. Some of these factors have been modeled before in isolation, but these models often predicted higher visual acuity than what was found in clinical trials [5, 6, 8, 14]. Therefore, using an established and psychophysically validated computational model of bionic vision may prove invaluable to generating realistic predictions of visual prosthetic performance.

4 CONCLUSION

The present work constitutes a first essential step towards immersive VR simulations of bionic vision. The proposed system has the potential to 1) further our understanding of the qualitative experience associated with different bionic eye technologies, 2) provide realistic expectations of bionic eye performance for patients, doctors, manufacturers, and regulatory bodies, and 3) accelerate the prototyping of new devices.

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