Enhancing Realism in Simulated Prosthetic Vision by Introducing Temporal Models

Julia Tomas-Barba, Alejandro Perez-Yus, Jesus Bermudez-Cameo, and Jose J. Guerrero

[1] Afiliación: Grupo de Robótica, Visión por computador e Inteligencia Artificial (RoPeRT)
Instituto de Investigación en Ingeniería de Aragón (I3A)
Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.
Tel. +34-976762707, e-mail: *j.tomas@unizar.es*

Abstract

Recent studies have demonstrated the effectiveness of computer vision techniques in assisting patients with visual prostheses. Evaluating these techniques requires the use of Simulated Prosthetic Vision (SPV). In this work, we propose an approach that introduces biologically-inspired temporal models to enhance the realism of SPV in real-time experimental frameworks.

Introduction

Visual prostheses restore vision by delivering electrical stimulation to the retina, generating neural signals interpreted as points of light called phosphenes. However, the perception of phosphenes differs significantly from natural vision, presenting spatial (elongation of phosphenes) and temporal (delayed onset and offset) effects. These distortions, combined with limitations such as low resolution and a small field of view, challenge the effectiveness of real prostheses.

Due to the limited number of patients, Simulated Prosthetic Vision (SPV), is used to address these challenges (see Figure 1). SPV replicates prosthetic behavior, enabling cost-effective and safe experimentation with healthy sighted individuals. This is crucial for researchers to understand user challenges and evaluate improvements on a large scale.

Therefore, an essential aspect of SPV is its realism in simulating real prostheses. While some researchers have studied both spatial [1] and temporal [2] effects, integrating the latter into real-time systems poses significant challenges, and as a result, they are often overlooked. In this article, we focus on enhancing SPV realism by introducing a temporal model into the system.

Methods

As demonstrated by previous experiments [3], the brightness of phosphenes exhibits an initial onset followed by gradual fading until they are turned off. In this section, we introduce a non-linear model to incorporate these effects into a SPV system.

We present a discretized temporal perception model, based on the non-linear equations from [3] due to its consistency with the biological nature of neural systems. Following this model, the brightness of the phosphene is obtained as a continuous signal (R_4) following the input electronic signal (F) according to these equations:

$$R_1\,(s) = F(s)\frac{1}{\tau_1 s + 1}$$

$$R_2\,(s) = R_1\,(s) - \varepsilon\left[\frac{1}{s}\frac{1}{\tau_2 s + 1}\right]F(s)$$

$$r_3\,(t) = \,[|r_2(t)|]^{\beta}$$

$$R_4\,(s) = R_3\,(s)\left(\frac{1}{\tau_3 s + 1}\right)^3$$

where β, τ_1, τ_2, $\tau_3$and ε are parameters obtained from experimentation with real patients [3].

To achieve real-time implementation, the model is constructed using a Look-Up Table (LUT) containing precalculated values. The LUT receives as input an array that includes the desired state of the phosphene in the current frame, as well as the corresponding information from the previous 9 frames. The current brightness of the phosphene in each frame is retrieved from the LUT by referencing the 10-value state vector, which encompasses both current and past desired luminosity levels. The desired luminosity level at each timestep depends on the computer vision algorithm applied to the camera image.

The 10-value state vector reflects the electrical stimulation received by an electrode over the last 200 ms, comprising 10 frames (20 ms per frame at a frequency of 50 Hz). Every 20 ms, a signal is defined that includes a biphasic pulse, with the pulse's amplitude varying according to the state of the electrode. In the case of the electrode being off (no brightness in the corresponding frame representation), no pulse is emitted. All possible electrical signals ($F(s)$) have previously been processed by the continuous model, to determine the current brightness of the phosphene.

Results

The proposed model, implemented in the RASPV system [4], demonstrates the significance of integrating temporal effects into SPV systems. Figure 2 illustrates that including temporal effects leads to a perception that is noisier and more confusing. This emphasizes the necessity of incorporating these effects for an accurate representation of real-life visual prosthesis user experiences. In addition, Figure 3 shows the difference between utilizing a 2-level and a 3-level luminosity input image. In this case, the third level has been used to highlight the contours of the objects, facilitating their detection.

Conclusions

In conclusion, this research represents a significant advancement in SPV systems, highlighting the importance of incorporating temporal effects to construct an accurate representation of the visual experience of real prosthesis users. Furthermore, the proposed model is flexible, enabling other users to adapt it with their own parameters or conditions. In future endeavors, we plan to conduct experiments aimed at elucidating and potentially mitigating the confusing nature of these effects. Our ultimate objective is to explore methods to eliminate these effects while optimizing electrical stimulation.

REFERENCES

[1] M. Beyeler, D. Nanduri, J.D. Weiland, et al. A model of ganglion axon pathways accounts for percepts elicited by retinal implants. *Sci Rep*, vol. 9, 9199, 2019.

[2] A. Pérez Fornos, J. Sommerhalder, L. da Cruz, J.A. Sahel, S. Mohand-Said, F. Hafezi, M. Pelizzone. Temporal Properties of Visual Perception on Electrical Stimulation of the Retina. *Invest. Ophthalmol. Vis. Sci.*, vol. 53, no. 6, pp. 2720-2731, 2012.

[3] A. Horsager, S.H. Greenwald, J.D. Weiland, M.S. Humayun, R.J. Greenberg, M.J. McMahon, G.M. Boynton, I. Fine. Predicting Visual Sensitivity in Retinal Prosthesis Patients. *Invest. Ophthalmol. Vis. Sci.*, vol. 50, no. 4, pp. 1483-1491, 2009.

[4] A. Perez-Yus, M. Santos-Villafranca, J. Tomas-Barba, J. Bermudez-Cameo, L. Montano-Olivan, G. Lopez-Nicolas, J.J. Guerrero. RASPV: A Robotics Framework for Augmented Simulated Prosthetic Vision. *IEEE Access*, vol. 12, pp. 15251-15267, 2024.

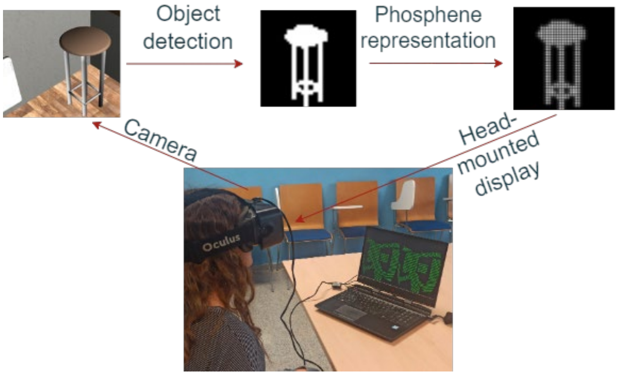

Figure 1. Diagram of an SPV system.

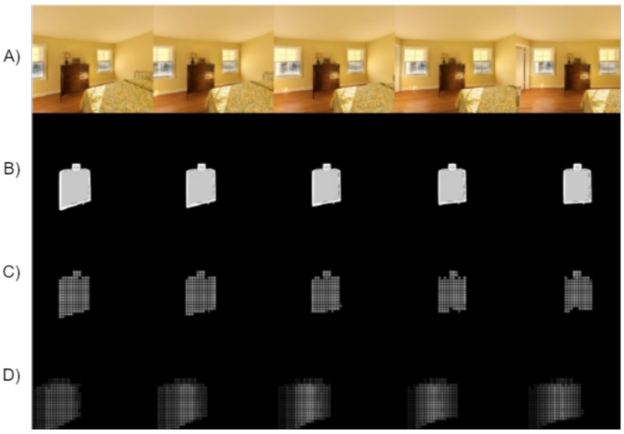

Figure 2. Outputs of different modes of the SPV system. A.RGB image. B. Segmented image. C. Perception with spatial model, and D. with spatiotemporal model.

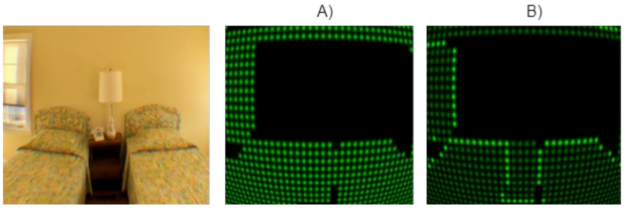

Figure 3. Output of the SPV system corresponding to a bedroom input image A. Two levels of luminosity. B. Three levels of luminosity for object detection.