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A spiking neural network model for obstacle avoidance in simulated prosthetic vision

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A B S T R A C T

Limited by visual percepts elicited by existing visual prosthesis, it's necessary to enhance its functionality to fulfill some challenging tasks for the blind such as obstacle avoidance. This paper argues that spiking neural networks (SNN) are effective techniques for object recognition and introduces for the first time a SNN model for obstacle recognition to assist blind people wearing prosthetic vision devices by modelling and classifying spatio-temporal (ST) video data. The proposed methodology is based on a novel spiking neural network architecture, called NeuCube as a general framework for video data modelling in simulated prosthetic vision. As an integrated environment including spiking trains encoding, input variable mapping, unsupervised reservoir training and supervised classifier training, the NeuCube consists of a spiking neural network reservoir (SNNr) and a dynamic evolving spiking neural network classifier (deSNN). First, input data is captured by visual prosthesis, then ST feature extraction is utilized in the low-resolution prosthetic vision generated by prostheses. Finally such ST features are fed to the NeuCube to output classification result of obstacle analysis for an early warning system to be activated. Experiments on collected video data and comparison with other computational intelligence methods indicate promising results. This makes it possible to directly utilize available neuromorphic hardware chips, embedded in visual prostheses, to enhance significantly their functionality. The proposed NeuCube-based obstacle avoidance methodology provides useful guidance to the blind, thus offering a significant improvement of current prostheses and potentially benefiting future prosthesis wearers.

1. Introduction

Degenerations of photoreceptor cells such as retinitis pigmentosa and age-related macular degeneration are devastating causes of vision loss. To restore vision to the blind, implantation of prostheses may become a treatment option in the encouraging neuroengineering field. Prostheses first transmit image data to an information processing unit. After electrode array gets stimulation patterns, surviving neural cells in the visual pathway can be electrically activated and visual perception can be stably evolved [15,34,48]. Such electrically induced visual sensations are called "phosphenes", conveying limited

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but useful visual information to the blind. Discernable phosphenes are usually generated in the following three locations: the visual cortex [12], the optic nerve [40], and the retina [24].

In recent years, retinal prostheses have gained much attention and obtained encouraging results. Epiretinal prostheses are implanted on the inner surface of retina, stimulating retinal ganglion cells and axons [44]. A 60-electrode epiretinal prosthetic system, the Argus II (Second Sight Medical Products, Inc, CA, USA), improved basic visual tasks such as orientation, mobility and letter reading [9,23]. Besides, subretinal prostheses are another kind of retinal devices implanted under the transparent retina to substitute the degenerated photoreceptors [31]. A subretinal prosthesis prototype with 1500 microphotodiodes was implanted in three subjects and demonstrated to be feasible by aiding them in some functional visual tasks [48].

Many technical factors such as implant packaging, electrode manufactory and biocompatibility limit the maximum number of implantable electrodes, leading to a low resolution visual perception with poor understanding. Faced with such a low sampling resolution resulting in a rigorous constraint to the information expressed by pixelized images, researchers find it necessary to optimize image content in order to assist the prosthesis wearers to perform better in visual tasks. More and more researches are concentrated on the how the implant recipient interprets visual information from electrical stimulation by simulation of prosthetic vision. In [8], the number of individual Chinese characters needed for accurate recognition by blind Chinese subjects was explored. Zhao et al. [46] found out that distortion, dropout percentage, and pixel size have impact on the recognition of Chinese characters. At the same time, many image processing strategies were proposed in simulated prosthetic vision. Parikh et al. [33] first applied saliency-based method and provided cues for region of interest detection in simulated vision. By exploring different face detection methods, Wang et al. [43] concluded that such image processing methods can highlight useful information thus improving visual perception of prosthesis wearers. In [42], background-subtraction-based technique was used to optimize the content of dynamic scenes of daily life. Han et al. [21] utilized feature extraction and image enhancement strategy to improve the accuracy and efficiency of object recognition. Aimed at highlighting the main object of a normal image, two different ways of pixelization [41] proved to be beneficial in daily object recognition tasks.

At first, obstacle avoidance was considered as the task of satisfying some control objective subject to non-intersection or non-collision position constraints in robotics. In [2], a vector field histogram method was developed and tested on an experimental mobile robot. A vision-guided local navigation system was proposed in [22] to compute a potential field over the robot heading, thus steering it towards the goal and away from obstacles. By utilizing a vision-based multi-person tracker, a dynamic obstacle map was generated in [13] to enable path planning in complex and highly dynamic scenes. However, all the above methods were not specially designed for the blind to fulfill the obstacle avoidance task. According to Dakopoulos and Bourbakis [10], there are already numerous navigation systems and tools for visually impaired individuals, among which white cane and dog guides are the most popular ones. In order to offer enough information such as speed, volume and distances to the visually impaired, a category of certain devices called electronic travel aids have been created. With the combination of different sensors such as sonars, laser scanners and cameras, information is gathered in multiple ways to guarantee the control of locomotion during navigation. Different from such existing systems, the proposed NeuCube-based obstacle avoidance system is developed as an extension of current visual prostheses, thus is free from different sensors.

As a new type of evolving connectionist systems, spiking neural networks have shown the power to deal with large and fast spatio/spectro temporal data. Various applications [29] include pattern recognition and early event prediction on EEG data, fMRI data, multisensory seismic data, ecological data, climate data, audio-visual data. For example, in [28] a novel evolving spiking neural network reservoir system(eSNNr) was proposed for personalised modelling of ST data and stroke prediction. Capecci et al. [4] utilized NeuCube SNN framework to analyze the functional changes in brain activity across different conditions and different groups of subjects. Doborjeh et al. [19] proposed a SNN-based methodology for learning and comparatively analyzing EEG data from healthy versus addiction treated versus addiction not treated subjects. Tu et al. [39] extended the use of the NeuCube to work on arbitrary stream data through a novel optimized mapping of temporal variables. Motivated by the above SNN applications, we propose to classify accurately and understand better the ST data in simulated prosthetic vision by utilizing NeuCube framework in a novel SNN architecture.

This study focuses on realizing the goal of obstacle avoidance for the blind based on existing visual prostheses. Unlike previous studies [21,33,41,43] which tried to optimize the content of phosphenes in order to improve the performances of visual tasks for the blind, our NeuCube-based obstacle avoidance system directly adds the obstacle analysis to the existing visual prostheses, deemed as an extension of such prostheses. The proposed obstacle avoidance method can make use of the down-sampled signal from information processing unit of epiretinal prostheses, which requires external image and data processing due to bypassing retinal image analysis, providing useful guiding information to the blind. Besides, our system is much simpler than the current navigation systems free of different sensors. To the best of our knowledge, we are the first to exclusively analyze the obstacle avoidance based on existing visual prostheses, thus showing a promising way to enhance the functionality of visual prostheses. Relatively high accuracy is obtained owing to the use of spiking neural network based NeuCube framework [29,30] inspired by how human brain processes ST data. Compared to other computational intelligence methods, NeuCube is adaptable to new data in an evolving way based on its own architecture and learning methodology. As a result, it's a natural idea to fulfill the brain-related obstacle avoidance task with the help of NeuCube, an evolving brain-like ST data processing machine.

The main contributions of this paper are three-folds: