Neurophysiology Based on Deep Neural Network under Artificial Prosthesis Vision

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Abstract. With the vigorous development of electronic technology and computer technology, as well as the continuous advancement of research in the fields of neurophysiology, bionics and medicine, the artificial visual prosthesis has brought hope to the blind to restore their vision. Artificial optical prosthesis research has confirmed that prosthetic vision can restore part of the visual function of patients with non-congenital blindness, but the mechanism of early prosthetic image processing still needs to be clarified through neurophysiological research. The purpose of this article is to study neurophysiology based on deep neural networks under simulated prosthetic vision. This article uses neurophysiological experiments and mathematical statistical methods to study the vision of simulated prostheses, and test and improve the image processing strategies used to simulate the visual design of prostheses. In this paper, based on the low-pixel image recognition of the simulating irregular phantom view point array, the deep neural network is used in the image processing strategy of prosthetic vision, and the effect of the image processing method on object image recognition is evaluated by the recognition rate. The experimental results show that the recognition rate of the two low-pixel segmentation and low-pixel background reduction methods proposed by the deep neural network under simulated prosthetic vision is about 70%, which can significantly increase the impact of object recognition, thereby improving the overall recognition ability of visual guidance.

Key words: Artificial Prosthesis Vision, Visual Prosthesis, Deep Neural Network, Image Processing

1. Introduction

As a hot technology for repairing visual function, artificial prosthesis brings hope to patients who are blind due to disease or trauma [1-2]. At present, deep neural networks not only have high accuracy, but also reduce the time cost of manual processing, and have become the main method of image recognition...
research [3-4]. Combined with artificial prosthesis based on deep neural network neurophysiology research is conducive to the restoration of vision after partial prosthesis implantation [5-6], meeting the needs of blind people in daily life, such as navigation, reading, object recognition and facial recognition [7-8].

In the research of neurophysiology based on deep neural network under artificial prosthesis vision, many scholars have studied it and achieved good results. For example, Cheng-Cheng proposed a piercing multi-electrode display optic nerve vision prosthesis [9]. Guo F proposed a computational low-pixelation model to detect salient features such as contrast, edge, orientation, and symmetry in an image, and give the detected area a relatively higher resolution [10].

In the process of research, this paper uses logic analysis to conduct an in-depth discussion on deep neural network processing images, expounds the advantages of deep neural network in feature extraction, and combines multidisciplinary knowledge such as mathematical morphology, physiology, neural network and fuzzy theory. It is proposed to use convolutional neural networks with high-resolution and high-level features that have both global and localized information to perform feature matching and image retrieval, which is suitable for obtaining better results in simulated prosthetic vision.

2. Neurophysiology Based on Deep Neural Network under Artificial Prosthesis Vision

2.1. Analysis of the Visual Characteristics of the Artificial Prosthesis

(1) Distorted phantom array

Wonderful sights of different size, brightness, shape and spatial distribution caused by electrical stimulation are the most basic components of prosthetic vision. However, the non-linearity of the anatomical structure of the retina will cause the spatial position of the prosthesis to be abnormal. The deformation of the ghost vision array will cause structural changes in the text and images under the prosthesis vision, which will affect the recognition of the implant. Therefore, it is necessary to introduce related algorithms to correct and optimize information expression to minimize the influence of distortion on text and object recognition.

(2) Missing rate

Adjusting the stimulation parameters of the visual prosthesis device can change the implantor's perception of phosphenes within the scope of the retinal topology. The stimulation thresholds of different neuronal cells are different. Once the stimulation intensity does not reach the threshold for phosphenes, there will be a missing point in the field of view at the electrode. If the electrode is in contact with degenerated or necrotic ganglion cells, the loss will also occur. Loss is also a very likely phenomenon after the implantation of the visual prosthesis.

2.2. Analysis of the Characteristics of Deep Neural Networks

The network topology of the convolutional neural network is in good agreement with the input image, which can eliminate unnecessary preprocessing and data reconstruction, and learn features directly from the original input image. Therefore, convolutional neural networks are widely used in the field of image recognition.
(1) Partial receptive field

The local receptive field is the local connection. The neurons in the hidden layer of the network are no longer connected to all input neurons, and only connected to the local input neurons. The neurons in the locally connected network are like the local receptive field. The neurons in the lower layer only need to perceive the local image information, and when the higher network level is reached, the local information is integrated and summarized to form the global information.

(2) Weight sharing

Corresponding to a feature map, there is only one corresponding convolution template. In a feature map, the convolution template is shared. Only a fixed-scale convolution kernel and the input feature map are used for shared convolution operation, thereby greatly reducing the amount of parameters. In the algorithm of weight sharing, a convolution kernel only extracts a feature of the input image or feature map. In order to make the information forwarded more abundant, different types of filters are added. Detector, that is, the method of convolution templates with different weight parameters, extracts different features from the same input image or feature map. Each filter deconvolves the image to obtain a mapping of different features of the image, and a rich variety of feature maps enhances the richness of extracted features.

(3) Spatial downsampling

In order to reduce the feature dimension in the process of learning features layer by layer in the network, a nonlinear spatial downsampling operation is usually added after convolution, also known as pooling operation. Pooling is a method of increasing the sliding step length of the filter in the image, thereby reducing the amount of calculation in this layer, reducing the scale of the output feature map and reducing the amount of calculation in the subsequent layers. The spatial sub-sampling operation makes full use of the local correlation characteristics of the image, reduces the amount of calculation, and increases the robustness of the convolutional neural network algorithm to translation.

2.3. Image Processing Methods Applied to Visual Prostheses

Low pixilation: Before the image is finally sent to the electrode, it must be simplified to the greatest extent, and pixel reduction is one of the necessary processes. In order to reduce the distortion caused by the average reduction of pixels, the image needs to be interpolated first. The cubic convolution method can overcome the deficiencies of the above algorithms, with high calculation accuracy, but a large amount of calculation. A simple and effective method is adopted to simplify the pixels. The dots with Gaussian distribution are selected to simulate the phantom viewpoint, and finally a low-pixel image composed of Gaussian dots will be obtained.

2.4. Low Pixelization Algorithm

According to the feedback from the implanter of the visual prosthesis, the phantom vision induced in the visual field is distorted after the retina prosthesis is implanted. In this paper, a two-dimensional mutually independent zero-mean Gaussian function is used to simulate the distorted phantom array. The probability distribution function is
\[ p(\Delta x, \Delta y) = \frac{1}{2\pi \sigma^2} \exp \left( -\frac{\Delta x^2 + \Delta y^2}{2\sigma^2} \right) \]  

(1)

Among them, \( \Delta x \) and \( \Delta y \) are the deviations in the horizontal and vertical directions, respectively, and the standard deviation \( \sigma \) determines the degree of uncertainty of the position of the phantom viewpoint, which is defined as follows:

\[ \sigma = kS \]  

(2)

\( k \) is the irregularity index, indicating the degree of distortion of the illusion array, the larger the \( k \) is, the more the illusion array is distorted. \( S \) is the center distance of two adjacent illusion points in the regular illusion array.

Taking into account the limited number of electrodes of the prosthesis and other reasons, it is a necessary step to reduce the pixels of the collected images. A simple and fast image processing strategy is adopted to simulate prosthetic vision based on the characteristics of clinical phantoms, and the image is low-pixelized into an image composed of Gaussian points. The formula is as follows:

\[ L = L_0 \times \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( -\frac{x^2}{2\sigma^2} \right) \]  

(3)

\( \sigma \) is valid for the brightness value within the standard deviation range, and the effective diameter of the Gaussian point is defined as \( d=2\times1.96\sigma \), which is the point size of the illusion.

3. Experimental Study of Neurophysiology Based on Deep Neural Network under Artificial Prosthesis Vision

3.1. Subjects

A total of 20 experimental subjects, 10 of whom participated in the image reading under the simulated irregular phantom array, and the other 10 participated in the image reading after pixel correction.

3.2. Experimental Materials

The experimental material library contains 50 images, all from the same batch of materials. Among them, these images involve 95% of the daily reading information, which ensures the commonness and legibility of the experimental materials and all images are of the same standard.

3.3. Optimization Method Design

According to the picture size, actual reading distance and camera parameters, the image is cropped to \( 25 \times 25 \) pixels. Then, the image is binarized, and then refined by skeleton extraction. Subsequently, the artificial irregular phantom array is used for low pixelation. According to existing research, the best reading angle under artificial prosthesis vision is \( 5^\circ \times 5^\circ \). According to these parameters, the resolution of the adjusted image is \( 45 \times 45 \) pixels. Such simulation stimulation fully retains the key features of the image and effectively reduces the problem of large changes in brightness and contrast that may be caused by different image processing strategies and microelectrode stimulation strategies in the actual prosthesis, making subsequent experiments more controllable. The results are also easier to analyze.
4. Investigation and Analysis of Neurophysiology Based on Deep Neural Network under Artificial Prosthetic Vision

4.1. Analysis of the Factors of Simulated Irregular Optical Phantom Array

As shown in Table 1, when the irregularity is 0.1 and 0.3, the recognition accuracy is more than 80%, and the artificial prosthesis can already meet the needs of normal reading.

| Irregularity index | Recognition rate | Missing rate |
|--------------------|------------------|--------------|
| 0.1                | 90%              | 10%          |
| 0.3                | 80%              | 20%          |
| 0.5                | 60%              | 40%          |
| 0.7                | 35%              | 65%          |
| 0.9                | 10%              | 90%          |

It can be concluded from Figure 1 that the recognition efficiency decreases with the increase of the irregularity index. When the irregularity index is 0.1, the recognition efficiency can reach 90%, which is a relatively high value. But when the irregularity index increased to 0.7, the recognition efficiency immediately dropped to 35%. When the irregularity index increases to a certain level, the distortion of the entire phantom array is very high, the distribution of points is very chaotic, and identification is basically impossible.
4.2. Recognition and Analysis of Single Objects under Artificial Prosthesis Vision

The ROI is used to process the resolution of the artificial prosthesis vision for the image, which are direct pixelization (DP), addition of separate pixelization (ASP), and background pixel shrink (BPS). In the case of low pixels, under the artificial prosthesis vision of $25 \times 25$ pixels, the processed recognition rate is significantly higher than the unprocessed recognition rate, and the unprocessed recognition rate is only 47%.

Table 2. Single object recognition data

| Image processing strategy | $25 \times 25$ Pixel | $45 \times 45$ Pixel |
|---------------------------|----------------------|----------------------|
| Unprocessed               | 47%                  | 36%                  |
| DP                        | 58%                  | 50%                  |
| ASP                       | 79%                  | 70%                  |
| BPS                       | 76%                  | 70%                  |

As shown in Figure 2, for a single object image, the recognition accuracy rate under DP is 50%. When the pixels are $45 \times 45$, the recognition rates of the four cases (unprocessed, DP, ASP, BPS) are significantly different from the results corresponding to $25 \times 25$ pixels. There is no obvious difference between the recognition accuracy of ASP and BPS, both are 70%.

5. Conclusions
As a new type of neuroprosthesis, visual prosthesis induces phosphenes of different sizes, brightness and shapes by electrically stimulating the retina, optic nerve or primary visual cortex, and relies on the organization of the phantom visual point to form a rich and complex pattern. Prosthetic vision repairs the visual perception and helps the implanter to obtain a more optimized visual experience. This paper analyzes the neurophysiology of artificial prosthesis vision based on deep neural networks, optimizes the image of the irregular phantom array, and proposes a new image processing strategy to segment low pixelation and background weakening low pixelation, showing its superior to direct low-pixelation in single-object recognition under low-resolution prosthetic vision. The object can be extracted from the graphics more accurately, and the outline of the object can be strengthened, so that the object recognition is more accurate and fast, and finally the recognition accuracy and efficiency are improved. This provides a basis for the study of image processing algorithms in simulated vision and the study of rehabilitation training after implantation of the prosthesis.

References

[1] Zhang C, Fagan C . Examining the role of IAPE on university students' civic perceptions and civic participation in Mainland China: Some hints from contemporary citizenship theory[J]. Citizenship Social & Economics Education, 2016, 15(2):117-142.

[2] Marianne, Rugk. Gilliam, Laura & Eva Gulv. Children of the welfare state: civilising practices in schools, childcare and families. viii, 290 pp. bibliogr. London: Pluto Press, 2017. £ 20.99 (paper)[J]. Journal of the Royal Anthropological Institute, 2019, 25(4):835-836.

[3] Padilla R U , Cartagena U D , NiÑ V , et al. Educational citizenship policy and formation of identities 1950-1980. Colombia.[J]. Memorias Revista Digital De Historia Y Arqueología Desde El Caribe, 2015, 25(1):280-305.

[4] Crum B . How to win the battle for survival as a school subject? Reflections on justification, objectives, methods and organization of PE in schools of the 21st century (Cómo ganar la batalla por la supervivencia como materia escolar Reflexiones sobre la justif[J]. Retos Nuevas Tendencias En Educación Física Deporte Y Recreación, 2016:págs. 238-244.

[5] Karabulatova I S , Barbash V V , Kotelnenets E A . The influence of technology on the formation of values, ideological and political values of youth: A cognitive dimension of the impact of anti-terrorist orientation sites[J]. Opcion, 2018, 34(85):810-824.

[6] Krivonos, D. And After That We All became Like Brothers: Emotions, Affectivity and Communication in a Pro-govermental Youth Movement in Russia[J]. Young, 2016, 24(2):102-117.

[7] Shala A , Grajcevci A . Examining the Role of Socioeconomic Status, Formal and Informal Education on Political Interest Levels among University Students[J]. Politics & Policy, 2018, 46(4).

[8] Kelcey J . Book Review: Political Socialization of Youth: A Palestinian Case Study by Janette Habashi[J]. Journal on Education in Emergencies, 2020, 6(1):200.
[9] Potomkina N. YOUTH CYBER SOCIALIZATION: A SOCIAL-PEDAGOGICAL APPROACH[J]. Social Work and Education, 2019, 6(3):269-284.

[10] Giordan G, Trophimov S, Breskaya O. Religious Socialization and Perception of Religious Freedom in Italy and Russia: Findings from a Comparative Research on Youth[J]. Studi di Sociologia, 2020(4):429-444.