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TO THE QUESTION OF PHYSICAL IMPLEMENTATION OF OPTICAL NEURAL NETWORKS

Abstract. The practical realization of optical neural networks with a small number of elements is considered. It is presented the application of the optical neural networks to the systems of adaptive optics. In this case, the usage pattern of the neural network assumes the impact on changes in the characteristics of the system. The application of adaptive optical system is a good example to design the automatic adjustment of the parabolic reflector when the sun moves across the sky. Since the parabolic reflectors used in solar power plants do not provide the necessary economic efficiency, this problem solving is relevant and actual. Using the adaptive optics systems allows to solve this problem due to the transition to light parabolic reflectors made of thin polymer film with a mirror coating. Fixing the shape of the parabolic reflector is ensured by the balloon system filled with a gas at the pressure slightly above atmospheric. The small weight of the parabolic reflector makes possible to use the servo-driven elements to develop a small torque. In particular, the balloon regulating elements are changing the volume of gas by solar heating. In this case, the controlling is created by focusing a portion of the solar energy entering the system on servo-driven elements. The paper is considering the different designs of optical neural networks. The optical neural network with thin optical transparency as a matrix of weights is presented as the most effective and easiest in implementation. In this case, each light source corresponding to the neurons of the first layer of the network is forming several images and the linear set of sources is transforming into the two-dimensional one. Optical summation of this matrix by columns ensures the performance of additive summation and this sets the work of the optical neurons on the second layer.
Keywords: neural network, optical signal, alternative energy, reflectors, control signals.

The work [1] outlines a strategy for the development of artificial intelligence systems in the Republic of Kazakhstan. A distinction of this strategy lies in the integrated interdisciplinary approach to the creation of all components of artificial intelligence systems (AI), focused on a wide range of practical applications, including the creation of molecular informatics systems [2, 3] based on the latest achievements in the field of physical chemistry of polymers [4, 5]. As is known, one of the most important areas of AI systems development is artificial neural networks (ANNs). Currently, ANNs are mainly presented as computer models and their physical implementation have to be considered [6-8].

As shown in [9, 10], one of the most promising directions for the physical implementation of ANNs lies in the creation of optical intelligent systems. An important step on this path is the development of optical ANNs. The advantage is presented in the possibility to work directly with a two-dimensional data array, which corresponds to the distribution of the light field in the input plane of the optical system. However, the development of optical neural networks is currently faced with well-defined difficulties.

One of them is the limitation of their practical application. Thus, this work will show an unexpected application of optical neural networks in the field of solar energy.

Namely, at present, solar energy is developing in several directions. In particular, despite significant progress in increasing the efficiency of solar photovoltaic panels, the development of solar collectors and concentrators remains relevant [11-14]. The design of such systems can be quite complex (including from the point of view of the used optical circuits [15]), however, devices based on the use of the historically first radiation concentrator - a parabolic reflector [16, 17] continue to be discussed. (The latter can be used, including, in combination with solar photovoltaic panels [18].)

The disadvantage of this type of systems is in sufficiently large weight of reflectors, which are being increased by area increasing. Accordingly, the large expenditure of energy is required on targeting the optical axis of the reflector to the Sun. In addition, the production of the reflector with typical characteristics is quite difficult; as a result, the cost of the energy increases. Moreover, the typical systems described in the literature [16, 17] are required to use servo-driven mechanisms, as well as rather complex control systems that ensure the tracking of the Sun's movement across the sky. As shown in [19], the problem of guidance of solar power systems in the Sun is very serious, and its decision to continue to be expended considerable effort. So, [20], in particular, describes a guidance system in which continuous movement of a solar power plant takes place, regardless of whether the Sun is in direct view or hidden behind clouds.

In terms of energy consumption, the most effective way to ensure the required orientation of the reflector in space lies in using thin polymer films. The scheme of the corresponding system is shown in figure 1.

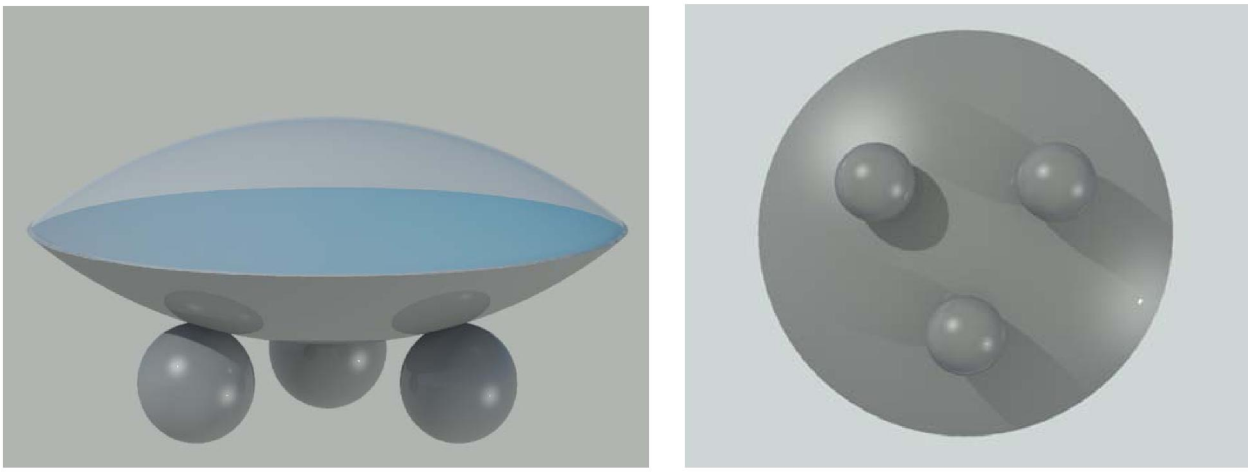


Figure 1

The reflector is presented as a gas-filled cylinder made of two parts. One part (1) is the reflector itself, which made of a polymer film with a reflective coating. The upper part is transparent and serves to ensure the given shape to the system when it is filled with gas at the pressure slightly higher than atmospheric (3). This Figure also schematically shows balloon servo-driven mechanisms (2).

Taking into consideration a small weight of the reflector itself, which can even be reduced due to the Archimedean force (which arises due to the fact that the gas inside the cylinder formed by the films (1) and (3) is heated during the work), it can be used the servo-mechanisms that perform only relatively small mechanical work.

In particular, such servomechanisms can be presented as balloon assemblies from polymeric elastic shell filled with gas or vapors of a slightly volatile liquid. When the gas is heated or the liquid is evaporated, the pressure will grow, the shell will be stretched; as a result, the system is able to ensure the rotation of the reflector to the required angle, as illustrated in figure 2. To protect the system from external influences (in particular from wind exposure), it is advisable to place it inside the containment shell as shown in figure 2. Here is shown the reflector (1) which is attached through the rods (3) to the assembly where the working body (2) heated by focused solar radiation is placed.

The entire system is situated inside the transparent protective sheath (4), which can also be made as a balloon from the transparent polymer film and filled with gas at a pressure slightly above atmospheric. Figure 2b shows the position of the focusing system during the rotation due to the servo-driven balloon system, which changes its volume heating by solar radiation. It should be emphasized that in this figure the servo-driven balloon system is shown schematically in the form of spheres for the sake of clarity; however, it is more convenient to use more complex geometry in order to optimize the response of systems to changes of temperature.

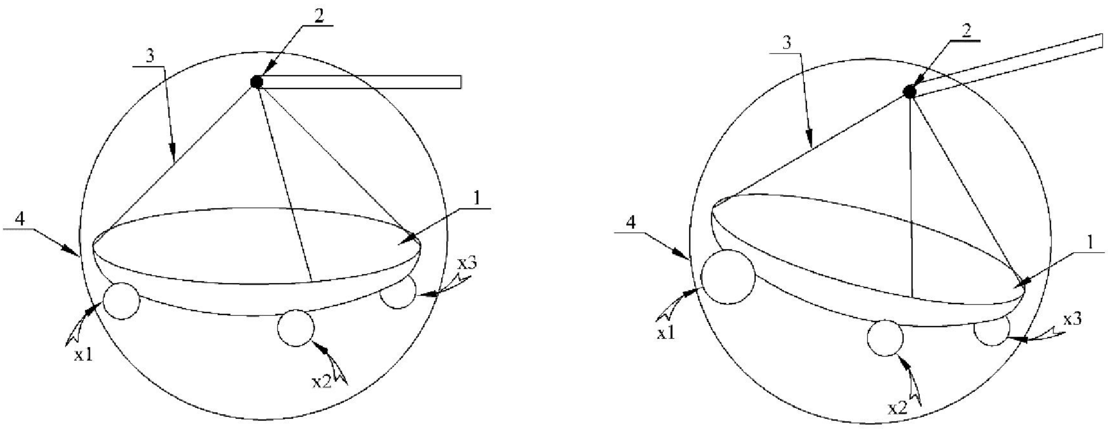


Figure 2a, 2b

Thus, the balloon parabolic reflectors really allow to make a device from the most cheap and light-weight materials that can be used in solar energy with a significant reduction of the cost.

The important element of the system is to provide the change in the orientation of the reflector while the Sun is moving across the sky. As noted above, the typical systems use control of complex software systems that take into account the geographical location of the reflector. However, this task can also be solved by the systems of adaptive optics, the system that provides automatic orientation of the reflector due to the temperature changes of the balloon system (in this very case). In other words, part of the solar energy entering the system is directed to servo-driven cylinders, which ensures the correct orientation of the reflector in automatic mode without using any additional control devices.

Thus, the considered system works due to the unequal heating of the three control elements. Since the temperature of the control elements is determined by solar radiation this example provides a convenient illustration of the possibility to use practically the optical neural networks. Indeed, the solar radiation from the control elements must be transformed to ensure the heating all three elements corresponding to the specified functioning of the device as a whole.

It should be emphasized that this example is used only to demonstrate the fact that the optical neural networks can be used to immediately generate control signals. It is significant that in this very case there is no need to use nonlinear optical elements that have to be introduced into the optical neural network when it is considered as a system intended only for information processing. In this case, the control assemblies with control optical (thermal) signals act as the nonlinear elements.

Neural networks are currently primarily used as information processing means. The vast majority of existing neural networks is presented as nothing more than computer programs.

At the same time, as it is shown in this work, the neural networks, even with a relatively small number of elements, can be used in automatic control systems as the assemblies that ensure the formation of effects that physically implement one or another algorithm of executive programs.

Optical neural network (in case of the physical implementation) has the advantage to work directly with two-dimensional data array. This is illustrated in figure 1, which schematically shows three light sources acting as neurons of the first layer and three radiation detectors acting as nonlinear elements of the neurons of the second layer of the network. In this case, the radiation from each source by three different optical elements is focused on each receiver. In order not to clutter up the drawing, it is shown the course of the rays only for the 1st and 3rd optical elements associated with each light source.

In the situation when the focusing optical elements have different transmission functions, it is easy to see that this kind of system performs additive summation of the original signals. In other words, the focusing elements together with the radiation detectors perform the same operations as the formal neurons of any classical artificial neural network.

Figure 3 is presented only to illustrate the nature of the operation of the optical neural networks. The advantage of this system lies in only visibility, and its technical implementation is very complicated due to the necessity of using a large number of focusing elements. It is much more easier to develop the physical implementation of the optical neural network by using the Fourier transforms of the lens (figure 4).

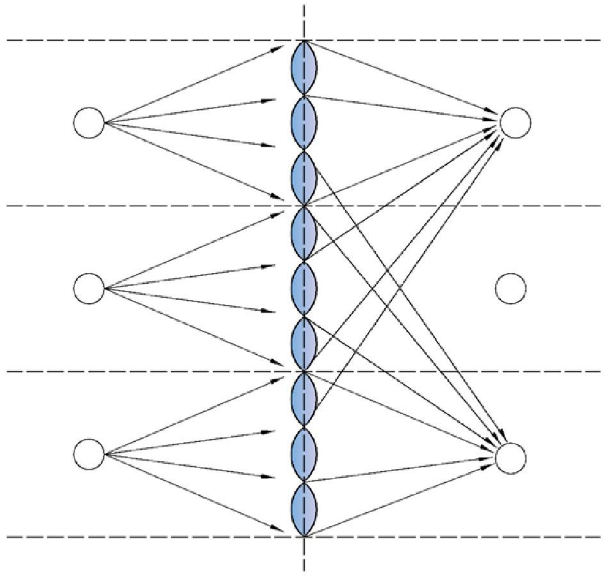


Figure 3

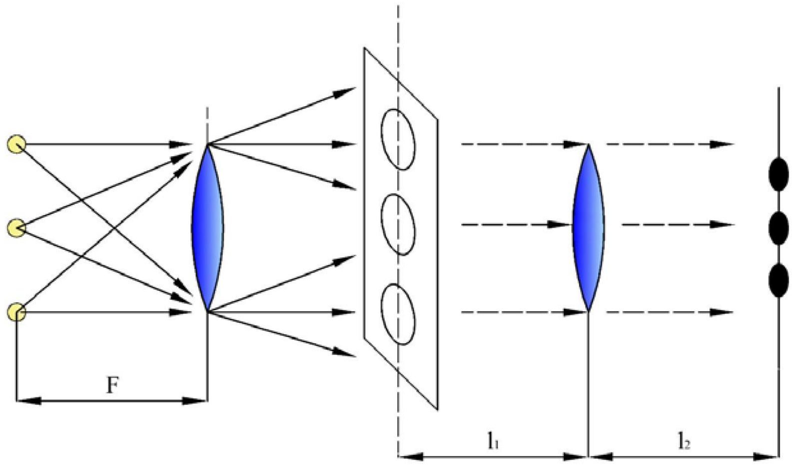


Figure 4

The figure also shows the three light sources that are placing in the focal plane of the input lens. The lens converts the radiation of each point source into a plane wave, which propagates at a certain angle to the optical axis; this angle is determined by the distance from the point source to the optical axis. Accordingly, the distribution of light intensity occurs at each point of the screen located behind the lens L1; it is determined by the superposition of the contributions from all these plane waves. Further, it is possible to ensure the construction of the screen’s holes by using the L2 lens. The radiation intensity corresponding to this image will also be the sum of the contributions from point sources.

From the point of using the system as a neural network, the disadvantage lies in the fact that the contribution from point sources does not have adjustable weights. It can be eliminated by providing a non-uniform diagram of the point sources used as the neurons of the first layer.

However, providing this diagram of the light point sources would not be a non-trivial task. Thus, taking into consideration that at the early stages of the implementation of optical neural networks there is no need to work with a large number of neurons, the following modification of the optical ANN is proposed.

The basis of this modification is about the optical element shown in figure 5. This optical element is actually made as a set of lenses arranged in a ruler from the single blank by the method of stamping or casting.

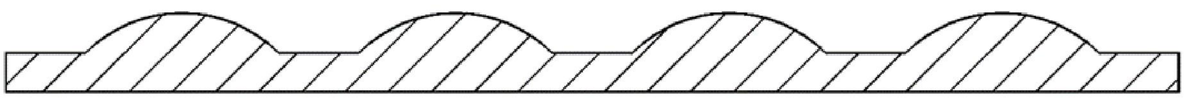


Figure 5

By applying such element, it is possible to develop the optical neural network using the fact that the set of light sources playing the role of inputs to neural networks located along a certain line appears as the set of dimension 1. This set can be displayed on the screen that appears as the set of dimension 2. This conditiom meets the nature of the connection between the number of network neurons and the number of weight coefficient; the number of weights is equal to the square of the number of neurons in the Hopfield neuroprocessor.

This very implementation of the system is shown in figure 6. Figure 6a shows the nature of the radiation conversion by the set of point sources of the optical element, which is shown in figure 5. The figure emphasizes that the optical element creates an image of sources that are also located along a straight line.

Figure 6b demonstrates how the optical elements are used to expand the linear set of sources into the two-dimensional set. The top view of the system is considered in the Figure. The number (1) marks the entire line of the optical sources of the original radiation. The number (2) marks the set of optical elements that is shown in figure 5. The system also includes the screen made as optical transparency, focusing elements (4) and radiation receivers (5) presented as the control nodes of the device (for example, nodes providing the orientation of the parabolic mirror on the Sun). Each optical element (2) creates its own system of images of the point sources of the screen (3).

The result of this conversion is illustrated in figure 6c. It shows the individual columns formed by the images of the original light sources presented because of the construction of the image elements (2). The screen (3) is made as optical transparency and the transmittance of its individual sections is non-uniform. In an extreme case, this screen may be made as a mask with holes corresponding to the non-zero weights of the neural network.

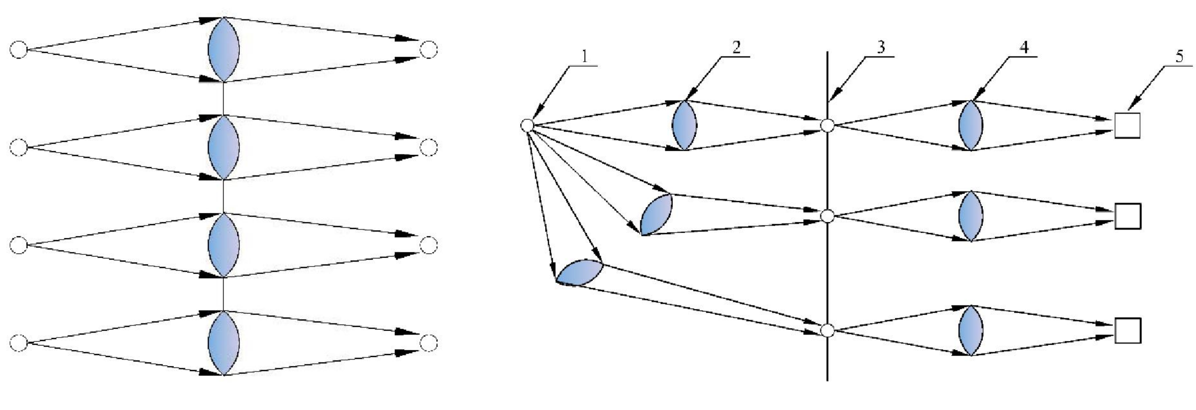
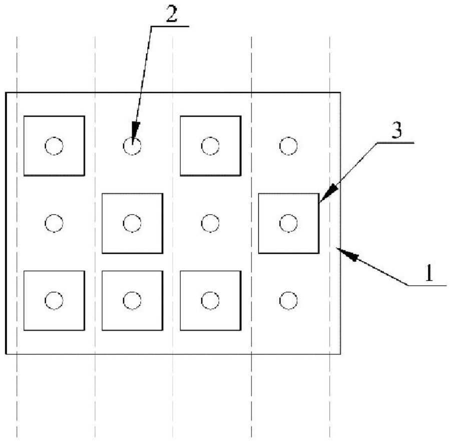


Figure 6a, 6в



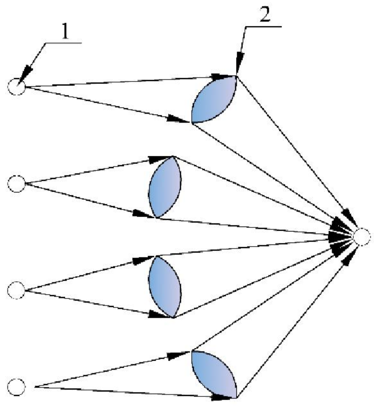


Figure 6c, 6d

Hereafter, the radiation generated by each column enters the focusing elements (4) which form the image on the receivers (5). The focus is illustrated in figure 6g. In other words, the receiver has the light created by the secondary sources forming the column of the matrix corresponding to the intensity distribution on the screen of figure 6c. Optical elements (4) can also be unified and produced by stamping or casting from relatively cheap polymeric optical transparent materials.

Thus, this paper shows the opportunity to transform existing approaches to the implementation of optical neural networks. The proposed approach allows to remove the problem of the inclusion the nonlinear optical elements to the composition of the ANN since the signals generated by such network are directly fed to the nodes that execute commands. In other words, final elements are working as non-linear converter that performs certain functions. The approach also means using the neural networks with a small number of elements. The implementation of the optical neural networks can be carried out on the basis of the transformation of one-dimensional data array to two-dimensional one. It allows using the optical transparencies as the classical means of information processing for physical optics.

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ОПТИКАЛЫҚ НЕЙРОНДЫҚ ЖЕЛІЛЕРДІ ФИЗИКАЛЫҚ ІСКЕ АСЫРУ ТУРАЛЫ МӘСЕЛЕГЕ

Аннотация. Салыстырмалы түрде аздаған элементтерден тұратын оптикалық нейрондық желілерді практикалық пайдалану мүмкіндіктері қарастырылады. Мұндай оптикалық нейрондық желілер адаптивті оптика жүйесінде қолданылуы мүмкін. Бұл жағдайда нейрондық желіні пайдалану сипаты жүйенің сипаттамаларын өзгертуді қамтамасыз ететін әсерді қалыптастырады. Мұндай тәсілдемені қолдану мысалы – күннің кездейсоқ жылжуы кезінде параболалық шағылдырғышты автоматты түрде құруға арналған адаптивті оптикалық жүйе. Бұл міндетті шешу өзекті болып табылады, өйткені қазіргі уақытта гелиоқондырғыларда қолданылатын параболалық шағылыстырғыштар қажетті экономикалық тиімділікті қамтамасыз етпейді. Адаптивті оптика жүйелерін пайдалану бұл проблеманы айналы жабыны бар жұқа полимерлі пленкадан жасалған жеңіл параболалық шағылыстырғыштарға өту есебінен шешуге мүмкіндік береді. Бұл жағдайда параболалық шағылдырғыштың нысанын бекіту атмосфералық қысымнан біршама асатын қысым кезінде газбен толтырылған баллон жүйесін пайдалану есебінен қамтамасыз етіледі. Параболалық шағылыстырғыштың салмағы шағын айналмалы нүктені дамытатын сервожетек элементтерін пайдалануға мүмкіндік береді. Атап айтқанда, бұл баллонды реттеуші элементтерді пайдалануға мүмкіндік береді, олардың көлемі олардағы газды күн жылуымен қыздыру кезінде өзгереді. Бұл жағдайда басқару әсері сервожетекті элементтерде жүйеге түсетін күн энергиясының бөлігін фокустау есебінен жасалады. Жұмыста оптикалық нейрондық желілердің әртүрлі конструкциясының нұсқалары қарастырылады. Сонымен қатар, ең тиімді салмақ коэффициенттерінің матрицасы ретінде жұқа оптикалық транспарантты пайдаланатын оптикалық нейрондық желі болып табылатыны көрсетілді. Бұл жағдайда желінің бірінші қабатының нейрондарына жауап беретін бастапқы жарық көздерінің әрқайсысы бірнеше бейнелерді қалыптастырады, нәтижесінде желілік көптеген көздер екі өлшемді болып өзгереді. Бұл матрицаны бағандар бойынша оптикалық қосу аддитивті қосу операциясының орындалуын қамтамасыз етеді, ол екінші қабатты оптикалық нейрондардың жұмысын көрсетеді.

Түйін сөздер: нейрондық желі, оптикалық сигнал, баламалы энергетика, шағылыстырғыштар, басқару сигналдары.

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К ВОПРОСУ О ФИЗИЧЕСКОЙ РЕАЛИЗАЦИИ ОПТИЧЕСКИХ НЕЙРОННЫХ СЕТЕЙ

Аннотация. Рассматриваются возможности практического использования оптических нейронных сетей, содержащих сравнительно небольшое количество элементов. Показано, что оптические нейронные сети такого рода могут найти применение в системах адаптивной оптики. В этом случае характер использования нейронной сети предполагает, что она формирует воздействие, обеспечивающее изменение характеристик системы. Примером применения такого рода подхода является адаптивная оптическая система, предназначенная для автоматической подстройки параболического отражателя при перемещении солнца по небосклону. Решение данной задачи является актуальным, так как в настоящее время параболические отражатели, используемые в гелиоустановках, не обеспечивают нужной экономической эффективности. Использование систем адаптивной оптики позволяет решить данную проблему за счёт перехода к легким параболическим отражателям, выполненным из тонкой полимерной пленки с зеркальным покрытием. Фиксация формы параболического отражателя в данном случае обеспечивается за счёт использования баллонной системы, заполненной газом при давлении, несколько превышающим атмосферное. Малый вес параболического отражателя позволяет использовать сервоприводные элементы, развивающие небольшой вращательный момент. В частности, это позволяет использовать баллонные регулирующие элементы, объем которых изменяется при нагреве находящегося в них газа солнечным теплом. Управляющее воздействие в данном случае создаётся за счёт фокусировки части солнечной энергии, поступающей в систему на сервоприводных элементах. В работе рассматриваются варианты различной конструкции оптических нейронных сетей. Показано, что наиболее эффективным с точки зрения простоты реализации является оптическая нейронная сеть, использующая в качестве матрицы весовых коэффициентов тонкий оптический транспарант. В данном случае каждый из исходных источников света, отвечающих нейронам первого слоя сети, формирует несколько изображений, в результате чего линейное множество источников преобразуется в двумерное. Оптическое суммирование данной матрицы по столбцам обеспечивает выполнение операции аддитивного суммирования, которое задает работу оптических нейронов второго слоя.

Ключевые слова: нейронная сеть, оптический сигнал, альтернативная энергетика, отражатели, управляющие сигналы.

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