PULSE-WIDTH MODULATION AS A NEW HYGIENIC FACTOR DETERMINING THE VISUAL COMFORT OF MODERN SCREENS

Kurgansky AM ✉

National Medical Research Center for Children's Health, Moscow, Russia

The information revolution and intensive development of electronic devices take place in the recent decades. Furthermore, not so long ago such a hygienic factor, as the display luminance pulse-width modulation (PWM) capable of causing visual discomfort (PWM symptoms) in individuals with increased sensitivity to visual load, has become relevant. The main complaints include eye pain, headache, sometimes nausea, up to the inability to use such screens. Moreover, this characteristic can be peculiar not only to LED (AMOLED, etc.), but also to IPS displays due to the presence of the LED backlight layer. No regulation of the issue has led to the emergence of online resources on PWM and the problem of visual impairment, where users verify the data on their own, which suggests the relevance of the subject selected. The paper reports theoretical aspects of PWM, technical characteristics of displays with PWM; the approaches to PWM measurement are described; the possible ways to reduce visual discomfort are discussed. Furthermore, the paper describes the method to measure PWM of displays using a photo camera with the exposure time set to 1/20 s, along with the method testing results. It has been shown that further research focused on assessing the effects of PWM on vision and the development of the method for hygienic assessment of monitors and smartphone screens with PWM are required.

Keywords: pulse-width modulation, displays, screens, monitors, visual discomfort, visual fatigue, PWM symptoms

✉ **Correspondence should be addressed:** Alexander M. Kurgansky
Lomonosovsky prospect, 2, bld. 1, Moscow, 119991, Russia; kurgansk@yandex.ru

Received: 07.12.2023 **Accepted:** 16.03.2024 **Published online:** 28.03.2024

DOI: 10.24075/rbh.2024.093

ШИРОТНО-ИМПУЛЬСНАЯ МОДУЛЯЦИЯ КАК НОВЫЙ ГИГИЕНИЧЕСКИЙ ФАКТОР, ОПРЕДЕЛЯЮЩИЙ ЗРИТЕЛЬНЫЙ КОМФОРТ СОВРЕМЕННЫХ ЭКРАНОВ

А. М. Курганский ✉

Национальный медицинский исследовательский центр здоровья детей, Москва, Россия

В последние десятилетия происходят информационная революция и интенсивное развитие электронных устройств. При этом относительно недавно актуальным стал такой гигиенический фактор, как широтно-импульсная модуляция (ШИМ) свечения дисплеев, которая может вызывать зрительный дискомфорт (ШИМ-синдром) у людей с повышенной чувствительностью к зрительным нагрузкам. К основным жалобам можно отнести боль в глазах, головные боли, иногда чувство тошноты, вплоть до невозможности пользования такими экранами. При этом указанная характеристика экрана может быть свойственна не только LED (AMOLED и др.), но и IPS-дисплеям, в связи с наличием слоя светодиодной подсветки. Отсутствие регулирования этого вопроса привело к появлению Интернет-ресурсов, посвященных ШИМ и проблеме нарушения зрения, где пользователи уточняют информацию самостоятельно, что свидетельствует об актуальности выбранной темы. В настоящей работе рассмотрены теоретические аспекты ШИМ, технические характеристики дисплеев с ШИМ, описаны подходы к ее измерению, представлено обсуждение возможных путей снижения зрительного дискомфорта. Помимо этого приведены описание методики измерения ШИМ дисплеев с помощью фотоаппарата с выдержкой, установленной на 1/20 с, и результаты апробации методики. Показана необходимость дальнейших исследований по оценке влияния ШИМ на зрение и разработке методики гигиенической оценки ШИМ-мониторов и экранов смартфонов.

Ключевые слова: широтно-импульсная модуляция, дисплеи, экраны, мониторы, зрительный дискомфорт, зрительное утомление, ШИМ-синдром

✉ **Для корреспонденции:** Александр Михайлович Курганский
Ломоносовский проспект, д. 2, стр. 1, г. Москва, 119991, Россия; kurgansk@yandex.ru

Статья получена: 07.12.2023 **Статья принята к печати:** 16.03.2024 **Опубликована онлайн:** 28.03.2024

DOI: 10.24075/rbh.2024.093

In the recent years, despite significant advances in the development and design of electronic devices, thanks to which the technical characteristics of even low-end devices have reached a decent quality determining high processing speed and large storage capacity that eventually have almost completely rid users of inconvenience when using computers and smartphones, the screen pulsation or the so-called pulse-width modulation (PWM) has turned out to be an unexpected factor causing severe visual discomfort in individuals showing increased sensitivity to visual load. This issue is extensively studied by both domestic [1–6] and foreign authors [7–11].

There are no data on the prevalence of PWM symptoms among both children and students in the available scientific literature, however, according to the popular science sources, the prevalence of PWM symptoms is 10–20% [12], which requires further investigation.

When describing the technical details, it should be noted that there are two methods to change screen brightness. The first approach is based on changing the screen luminance, when the light emitted by the source is continuous. The second approach is based on using PWM, when the light emitted by the screen has certain pulsation frequency. This means that there is some backlight flicker frequency (for example, 120 Hz), which, depending on the pulse length, i.e. the time for that the light-emitting diodes (LEDs) are turned on (on-off time ratio), determines the resulting light intensity of screen. The differences between the approaches are illustrated by Fig. 1.

The PWM symptoms can represent eye pain, eye fatigue, spasm of accommodation, headache, and nausea making it impossible to use the screen with PWM. In case of prolonged exposure, failure of the visual system adaptation causing temporary visual impairment can be observed.

It is important to consider that an LCD screen consists of liquid crystals not emitting, but only transmitting light. The liquid crystal layer has its own refresh rate (this parameter is usually specified in the screen technical characteristics). The underlying layer of LED backlight, in contrast, emits its own light, which is what leads to the emergence of PWM. This means that

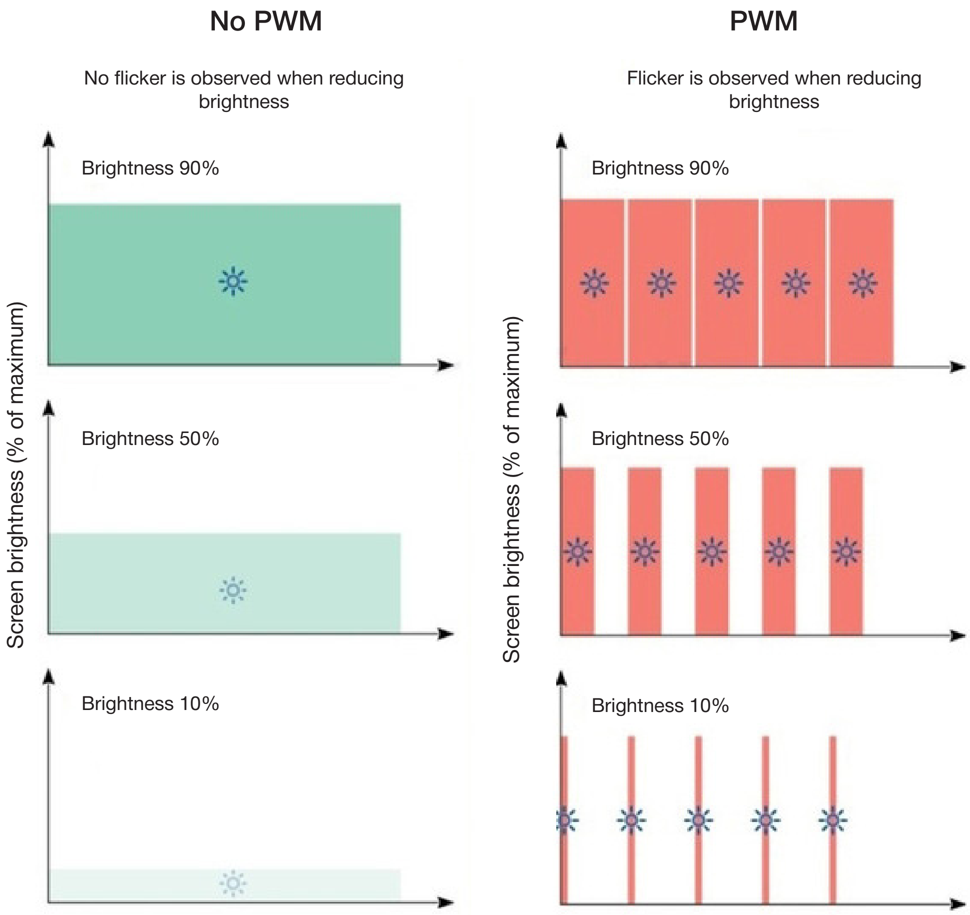

Fig. 1. Comparison of different techniques to change the screen brightness — through changing luminance (on the left) and applying PWM (on the right). The figure is taken from the free source [13].

the cause of PWM in LCD screens is the backlight flicker [14], not the screen refresh rate. Furthermore, manufacturers do not publish this parameter for commercial reasons, thereby creating a certain risk for the susceptible population when buying screens.

We have not found the reason, why the PWM technology is used in modern screens, since, as it was mentioned above, not all parameters are specified in the technical characteristics of screens. There is a number of opinions actively discussed on forums, such as 4PDA [15]: that in the recent years manufacturers have set the goal to create the screen that can be used in bright outdoor light and that such an innovation has significantly increased the screen brightness characteristics. Moreover, high screen brightness is associated with the characteristic noise of electromagnetic origin. Thus, to reduce the voltage resulting in such noise, manufacturers have probably taken the path of reducing the flicker rate, and that causes uncomfortable sensations in some proportion of the population.

The other, more grounded version is the change of the backlight technology from luminescent to LED, which has led to the emergence of PWM [14].

From a physiological point of view, PWM can be compared with the critical flicker fusion frequency (CFFF), when the eye stops recognizing pulsation with increasing frequency, and the estimated threshold value is about 60 Hz. Furthermore, there is a term “transient twinkle perception” (TTP) showing that the human eye is capable of recognizing a more high-frequency flicker under certain conditions [14].

The literature provides the data suggesting that the recommended safe PWM threshold should not drop below 200 Hz. Otherwise, such screens can cause visual discomfort [14].

GOST 33393–2015 “Buildings and structures” [16] provides a standard value of light pulsation in the workplace, which is 300 Hz. Furthermore, on sale there are more expensive screens with the PWM exceeding 2000 Hz that cause no visual discomfort. This probably represents a technical solution to the problem.

The author does not set a goal to substantiate the screen pulsation standards. However, it can be concluded that the screen PWM values of 100–120 Hz are undesirable and can cause visual discomfort in the susceptible part of the population. The paper provides the author’s opinion about the main available methods to assess PWM that is based on the results of testing the PWM measurement method by taking pictures of the screen in dynamics and the literature data.

Methods to determine PWM of the screen

The method developed by enthusiasts and distributed via Internet [17], which can be also found on the web-site of photographer Anatoly Lupashin, is of interest. In accordance with the method, screens of various designs (Huawei MateBook D14, HP Pavilion 14-ec002ur, Xiaomi 11 Light 5G NE, iPhone 11, 23-inch AOC monitors) with the table displayed were used to determine PWM (Fig. 2). The Canon EOS 2000D camera with the exposure time set to 1/20 s was used to perform shooting in motion (horizontal motion along the screen) aimed to obtain blurred vertical lines of the diagnostic table (Fig. 2). Then the image of vertical lines of the diagnostic table was visually assessed. When there was pulsation, the alternating light and darkened bands corresponding to the phases of the light-emitting diode pulsation of the screen could be seen

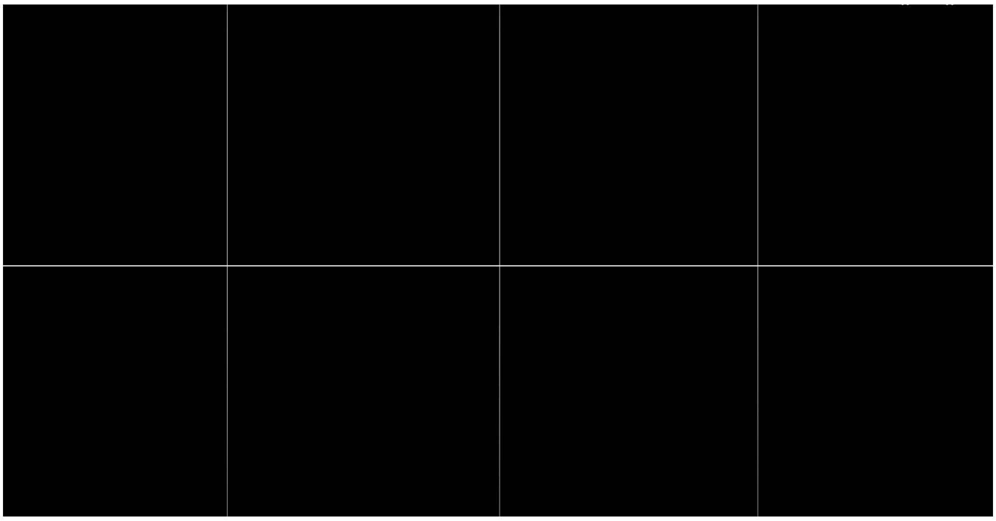

Fig. 2. Example of the table for PWM determination by taking pictures in dynamics

on the vertical lines. To quantify PWM, the number of bands was multiplied by the exposure time (20) to obtain the number of pulses per second (Hz).

Determining PWM of the screen is an important problem. The pulsation coefficient (C_p) is calculated using the following formula:

$$C_p = \frac{E_{max} - E_{min}}{2E_{av}}$$

where E is luminosity (lx). This means that the coefficient considers luminosity values only (maximum, minimum and average) and does not consider the oscillation frequency, therefore, this method involving the use of luminometer-pulsmeter is unsuitable for assessment of PWM.

Ideally, PWM should be assessed using an oscilloscope with a photosensor capable of plotting the screen luminosity oscillation curve. Unfortunately, such expensive units are not included in the list of devices for hygienic assessment of video display terminals (VDT). In this regard, in our case it was difficult to access such equipment. Furthermore, it is hard to find equipment of this type (oscilloscopes with photosensors) in the free market. There are papers (for example, the post published on Yandex Zen [18]) reporting that users have manufactured photosensors for smartphones on their own, however, this requires certain technical competence.

The lack of information about the presence of PWM in the data sheets of devices, as well as the method for hygienic examination of this factors, has led to the emergence of forums and websites focused on “combating PWM” (RTINGS.com), where enthusiasts test screens for PWM by themselves and people, ho have faced the problem of PWM, acquire information about the comfort of their desired device for vision, because in this category of users buying the screen with PWM can result in discomfort and inability to use the screen.

There are simple methods to determine PWM, such as the “pencil test” involving “waving” pencil in front of the screen or taking a video of the screen in the slow mode, which reveals the characteristic bands on the screen. However, these methods do not allow PWM quantification.

The author has tested a PWM measurement method involving taking pictures of the screen in dynamics using the available equipment. As a result, PWM values not exceeding 120 Hz (about 100 Hz) were obtained for the screens causing a subjective sensation of visual discomfort (Huawei MateBook

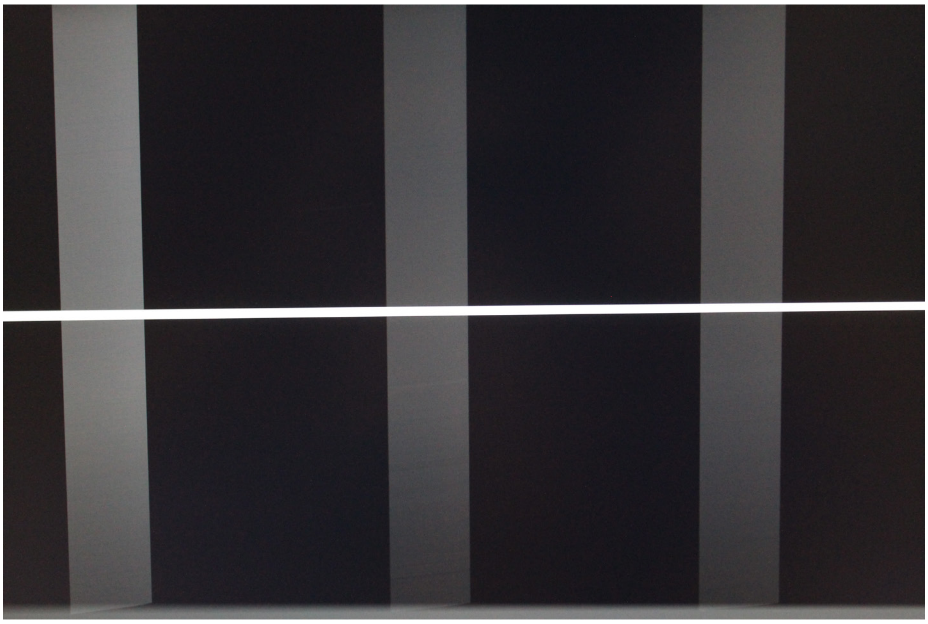

Fig. 3. Example of taking pictures in dynamics (23-inch AOC office monitor) — no PWM

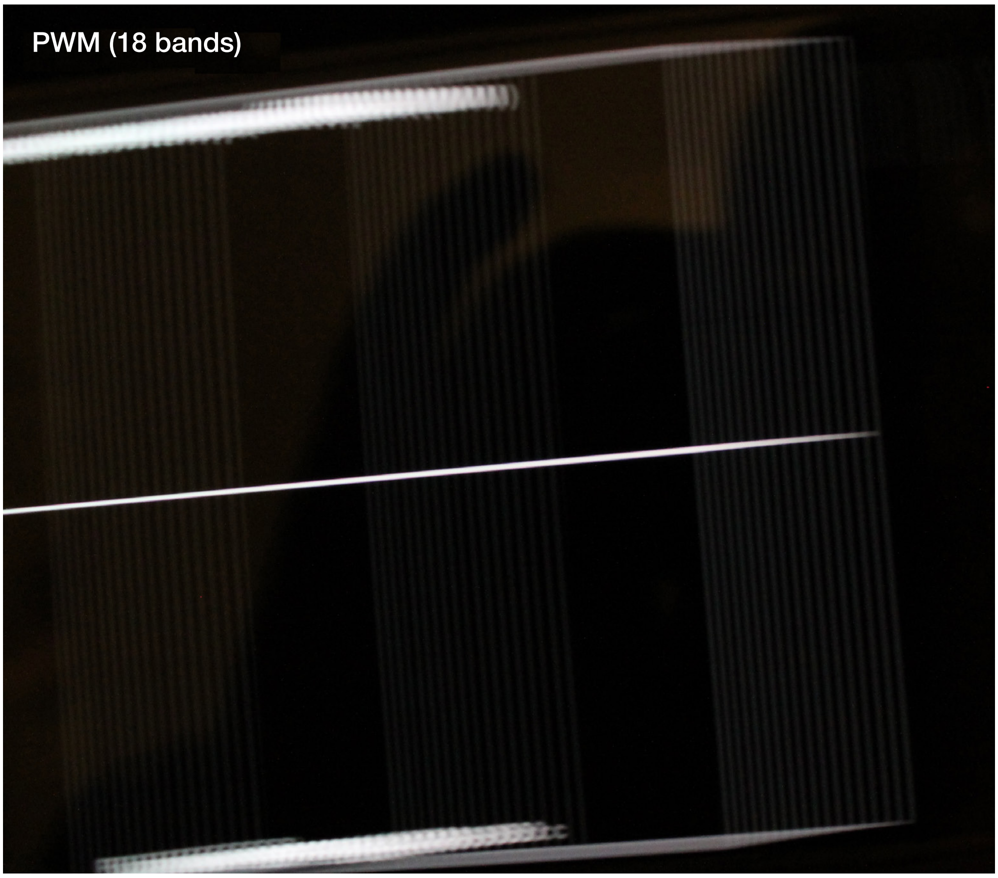

Fig. 4. Example of taking pictures in dynamics (Xiaomi 11 Light 5G NE) on an enlarged scale — PWM of 18 bands (360 Hz)

D14, HP Pavilion 14-ec002ur). Furthermore, there was no PWM at all or PWM exceeding 300 Hz reported for the screens characterized by subjective visual comfort (Fig. 3, 4).

Measures to reduce visual discomfort caused by PWM

The main measure is correct selection of monitor or replacement of the already existing device (if there are complaints). When using a laptop, it is recommended to connect an external screen. However, there are some other approaches that are not effective enough.

The method of increasing brightness to 100% can be found on many web-sites on "combating PWM". This, on the contrary, makes the light emitted by LEDs almost continuous and reduces pulsation, while the screen brightness is adjusted (reduced) at the expense of the contrast parameter. However, such an approach is not always effective. For example, increasing brightness to 100% on the Huawei MateBook D14 laptop led to the emergence of pronounced PWM and subjective sensation of eye pain. This suggests that, despite positive feedback from the Internet users, the approach cannot be used for all screen types.

Another approach is based on reducing the screen luminance through setting a dark theme of the system and browser. This also does not ensure a 100% efficiency of reducing visual discomfort, reducing it to some extent only.

Switching to the eye-protection mode of the monitor and reducing screen time are the important measures.

It is preferable to buy displays with the Flicker-Free [3], DC Dimming technology that smooth PWM [2] or the "office" displays with reduced brightness and contrast designed for the long-term use.

It is important to note that PWM is not the only factor determining visual discomfort. A combination of factors can lead to the fact that devices with PWM and relatively equal pulsation rate can be subjectively perceived differently. Perhaps, an important role in this is played by the blue light, image brightness and contrast. It is well known that adjustment of brightness and contrast is one of the methods to reduce the PWM negative effects [19]. Furthermore, for example, polarizing films represent an additional factor of the screen design capable of affecting vision [15]. It is polarizing films pasted on the screens and special filter goggles that have helped some users reduce visual discomfort, which also requires further Investigation [15].

Based on the foregoing it can be concluded that the likelihood of visual discomfort is low when using a screen with conventional design, while the use of the innovative screen containing LEDs is associated with the risk of severe visual discomfort, and the leading factor is PWM.

Thus, currently, LEDs are being introduced into screen designs everywhere, while the issue of the LEDs hygienic assessment remains unresolved. It is important to avoid the situations, when in pursuit of a high-quality image the technology causing visual discomfort in the susceptible population group is implemented. In this regard, further research in this field is necessary, along with comprehensive assessment of the factors determining the visual comfort of today's screens, since different factors can potentiate each other (for example, the combination of pulsation with high brightness and contrast (sharpness) of the screen, blue light), thereby causing severe visual discomfort.

CONCLUSION

Pulse-width modulation (PWM) of modern screens is a relevant hygienic factor that causes visual discomfort in the population group susceptible to visual load. Moreover, the number of domestic papers on the issue is extremely low; it is necessary to conduct research focused on the issue. Due to complaints, it is necessary to oblige the display manufacturers to specify the PWM parameter in the product technical documents at the legislative level. Furthermore, there is a need to study the prevalence of PWM symptoms among both students and children. Such studies combined with the analysis of technical information will make it possible to purchase safe equipment for school education. There is a need for hygienic studies aimed to substantiate the risk associated with exposure to PWM light emission of displays for the visual system. In the future it is recommended to develop the method and criteria for assessment of the PWM displays used by children and adolescents to be used in combination with assessment of other factors affecting visual comfort.

References

1. Sitnov KE. Issledovanie shirotno-impul'snoj moduljacii ZhK-jekranov i osvetitel'nyh priborov v ramkah prakticheskogo kursa po estestvoznaniju. Fizika v shkole. 2020; (S2): 208–11 (in Rus.).
2. Bojarshinov DV, Vanina AG. Vlijanie shirotno-impul'snoj moduljacii v displejah na cheloveka. V sbornike: Innovacionnye vektory cifrovizacii jekonomiki i obrazovanija v regionah Rossii. Stavropol', 2021: 75–9 (in Rus.).
3. Gaev LV, Simonov IN. Analiz problemy shirotno-impul'snoj moduljacii i poisk sposobov bor'by s nej. V sbornike: Nauka, innovacii i tehnologii: ot idej k vnedreniju. Materialy II Mezhdunarodnoj nauchno-prakticheskoj konferencii molodyh uchenyh. Komsomol'sk-na-Amure, 2022: 43–7 (in Rus.). DOI: 10.17084/978-5-7765-1521-7-2022-43.
4. Kudryashov AV, Kalinina AS, Yagovkin GN. Pulse width modulated LED light control and vision adaptation. Proceedings of the 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), St. Petersburg, Russia; 16–19 May 2017. St. Petersburg, 2017: 1–4. DOI: 10.1109/ICIEAM.2017.8076145.
5. Kudrjashov AV, Kalinina AS, Jarmolnik JuA., Sevostjanov GV. Pul'sacija sovremennyh istochnikov sveta i mobil'noe prilozhenie dlja ee ocenki. Vestnik NCBZhD. 2020; 1(43): 155–63 (in Rus.)
6. Makarenko AA, Loza NI. Zrenie i gadzhety. Uspehi v nauke i obrazovanii. Sbornik statej II Mezhdunarodnogo nauchno-issledovatel'skogo konkursa. Penza, 2023; 298–302 (in Rus.).
7. Mouli S, Palaniappan R. Toward a reliable PWM-based light-emitting diode visual stimulus for improved SSVEP response with minimal visual fatigue. J Eng. 2017; (2): 7–12. DOI: 10.1049/joe.2016.0314.
8. Kim Hs, Song GS, Ahn HB, Lee CY, Kim JH. A study on the effects of LED light's pulse width modulation on work concentration. In: Uden L, Heričko M, Ting IH, editors. Knowledge management in organizations. KMO 2015. Lecture notes in business information processing, vol. 224. Springer, Cham.; 2015. p. 550–60. DOI: doi.org/10.1007/978-3-319-21009-4_41.
9. Palaniappan R, Mouli S, Balli T, McLoughlin I. On the mental fatigue analysis of SSVEP entrainment; Proceedings of the 2018 2nd International Conference on BioSignal Analysis, Processing and Systems (ICBAPS); Kuching, Malaysia. 24–26 July 2018; Piscataway Township, NJ, USA: IEEE; 2018. p. 19–24. DOI: 10.1109/ICBAPS.2018.8527400.
10. Kim M. Assessment of the effect on the human body of the flicker of OLED displays of smartphones. J Inf Disp. 2021; 22 (4): 269–74. DOI: https://doi.org/10.1080/15980316.2021.1950854.
11. Wu Z, Wang l, Tu Y, et al. Effect of PWM dimming frequency of OLED smartphones on visual fatigue. International Conference on Display Technology. 2023; 54 (S1): 379–82. DOI: 10.1002/sdtp.16308.
12. Delfanto [Internet]. ShIM jekrana; 2018–2024 [cited 2023 Dec 1]. (In Rus.). Available from: https://delphanto.ru/blog/shim-ekrana/.
13. Smart-Lab [Internet]. ShIM-jeffekt, dlja teh kto sobralsja pokupat' monik ili nout; 2018 [cited 2023 Dec 1]. Available from: https://smart-lab.ru/blog/495560.php.
14. Chistobaev DV, Krasnobaev EA. Analiz metodov upravlenija svetodiodnoj podsvetkoj displejnyh ustrojstv. Cifrovaja transformacija. 2018; 2 (3): 60–4 (in Rus.).
15. Forum 4PDA [Internet]. Vtoroj smartfon — boljat glaza. Pomogite s vyborom. Ne mogu pol'zovat'sja novymi smartfonami. Proshu pomoshhi s nastrojkami ili vyborom ustrojstva. p.27; 2021 [cited 2023 Dec 1]. (In Rus.). Available from: https://4pda.to/forum/index.php?showtopic=943228&st=520.
16. GOST 33393–2015 Zdanija i sooruzhenija. Metody izmerenija kojefficienta pul'sacii osveshhennosti. (In Rus.).
17. Baker S. Pulse width modulation [Internet]. 2018 [cited 2023 Dec 1]. Available from: https://www.tftcentral.co.uk/articles/pulse_width_modulation.htm.
18. Jandeks Dzen [Internet]. Kak s pomoshh'ju smartfona proverit' televizor na vrednoe ShIM mercanie. Tehnicheskie sovety i ne tol'ko. 2021 [cited 2023 Dec 1]. (In Rus.). Available from: https://dzen.ru/a/YGxFB-35zWqQ7Zwo.
19. Ajzjatova MV, Aleksandrova IJe, Lashneva IP, Kurganskij AM. Obosnovanie optimal'nyh parametrov jarkosti jekrana interaktivnoj paneli dlja snizhenija riska obshhego i zritel'nogo utomlenija shkol'nikov. Analiz riska zdorov'ju. 2023; (1): 46–54 (in Rus.).

Литература

1. Ситнов К. Е. Исследование широтно-импульсной модуляции ЖК-экранов и осветительных приборов в рамках практического курса по естествознанию. Физика в школе. 2020; (S2): 208–11.
2. Бояршинов Д. В., Ванина А. Г. Влияние широтно-импульсной модуляции в дисплеях на человека. В сборнике: Инновационные векторы цифровизации экономики и образования в регионах России. Ставрополь, 2021: 75–9.
3. Гаев Л. В., Симонов И. Н. Анализ проблемы широтно-импульсной модуляции и поиск способов борьбы с ней. В сборнике: Наука, инновации и технологии: от идей к внедрению. Материалы II Международной научно-практической конференции молодых ученых. Комсомольск-на-Амуре, 2022: 43–7. DOI: 10.17084/978-5-7765-1521-7-2022-43.
4. Kudryashov AV, Kalinina AS, Yagovkin GN. Pulse width modulated LED light control and vision adaptation. Proceedings of the 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), St. Petersburg, Russia; 16–19 May 2017. St. Petersburg, 2017: 1–4. DOI: 10.1109/ICIEAM.2017.8076145.
5. Кудряшов А. В., Калинина А. С., Ярмольник Ю. А., Севостьянов Г. В. Пульсация современных источников света и мобильное приложение для ее оценки. Вестник НЦБЖД. 2020; 1(43): 155–63.
6. Макаренко А. А., Лоза Н. И. Зрение и гаджеты. Успехи в науке и образовании. Сборник статей II Международного научно-исследовательского конкурса. Пенза, 2023; 298–302.
7. Mouli S, Palaniappan R. Toward a reliable PWM-based light-emitting diode visual stimulus for improved SSVEP response with minimal visual fatigue. J Eng. 2017; (2): 7–12. DOI: 10.1049/joe.2016.0314.
8. Kim Hs, Song GS, Ahn HB, Lee CY, Kim JH. A study on the effects of LED light's pulse width modulation on work concentration. In: Uden L, Heričko M, Ting IH, editors. Knowledge management in organizations. KMO 2015. Lecture notes in business information processing, vol. 224. Springer, Cham.; 2015. p. 550–60. DOI: doi.org/10.1007/978-3-319-21009-4_41.
9. Palaniappan R, Mouli S, Balli T, McLoughlin I. On the mental fatigue analysis of SSVEP entrainment; Proceedings of the 2018

2nd International Conference on BioSignal Analysis, Processing and Systems (ICBAPS); Kuching, Malaysia. 24–26 July 2018; Piscataway Township, NJ, USA: IEEE; 2018. p. 19–24. DOI: 10.1109/ICBAPS.2018.8527400.
10. Kim M. Assessment of the effect on the human body of the flicker of OLED displays of smartphones. J Inf Disp. 2021; 22 (4): 269–74. DOI: https://doi.org/10.1080/15980316.2021.1950854.
11. Wu Z, Wang l, Tu Y, et al. Effect of PWM dimming frequency of OLED smartphones on visual fatigue. International Conference on Display Technology. 2023; 54 (S1): 379–82. DOI: 10.1002/sdtp.16308.
12. Дельфанто [Интернет]. ШИМ экрана; 2018–2024 [дата обращения 1.12.2023]. URL: https://delphanto.ru/blog/shim-ekrana/.
13. Smart-Lab [Интернет]. ШИМ-эффект, для тех кто собрался покупать моник или ноут; 2018 [дата обращения 1.12.2023]. URL: https://smart-lab.ru/blog/495560.php.
14. Чистобаев Д. В., Краснобаев Е. А. Анализ методов управления светодиодной подсветкой дисплейных устройств. Цифровая трансформация. 2018; 2 (3): 60–4.
15. Форум 4PDA [Интернет]. Второй смартфон — болят глаза. Помогите с выбором. Не могу пользоваться новыми смартфонами. Прошу помощи с настройками или выбором устройства. с.27; 2021 [дата обращения 1.12.2023]. URL: https://4pda.to/forum/index.php?showtopic=943228&st=520.
16. ГОСТ 33393–2015 Здания и сооружения. Методы измерения коэффициента пульсации освещенности.
17. Baker S. Pulse width modulation [Internet]. 2018 [cited 2023 Dec 1]. URL: https://www.tftcentral.co.uk/articles/pulse_width_modulation.htm.
18. Яндекс Дзен [Интернет]. Как с помощью смартфона проверить телевизор на вредное ШИМ мерцание. Технические советы и не только. 2021 [дата обращения 1.12.2023]. URL: https://dzen.ru/a/YGxFB-35zWqQ7Zwo.
19. Айзятова М. В., Александрова И. Э., Лашнева И. П., Курганский А. М. Обоснование оптимальных параметров яркости экрана интерактивной панели для снижения риска общего и зрительного утомления школьников. Анализ риска здоровью. 2023; (1): 46–54.