UDC: [37.018.43:53]:004.932.2(045)

Ihor Chernetckiy
PhD of Pedagogical Sciences,
Head of the Department for Creating Educational and Thematic Knowledge Systems
National Center «Junior Academy of Sciences of Ukraine», Kyiv, Ukraine
ORCID ID 0000-0001-9771-7830
manlabkiev@gmail.com

Iryna Slipukhina
Doctor of Pedagogical Sciences, Professor, Chief researcher
National Center «Junior Academy of Sciences of Ukraine», Kyiv, Ukraine
ORCID ID 0000-0002-9253-8021
slipukhina2015@gmail.com

Sergii Mieniailov
PhD of Pedagogical Sciences, Docent, Associate Professor of the Department of General and Applied Physics
National Aviation University, Kyiv, Ukraine
ORCID ID 0000-0002-4871-311X
msm56msm@gmail.com

Nataliia Kurylenko
PhD of Pedagogical Sciences, Lecturer of the Department of Physics and Astronomy
Kherson State University, Kherson, Ukraine
ORCID ID 0000-0002-1083-3247
kurylenko.n.v1976@gmail.com

DISTANCE EDUCATION METHODS: VIDEO ANALYSIS IN TEACHING PHYSICS

Abstract. Formation of the skills of conducting an experiment and analyzing its results during laboratory work in natural science has always been an important didactic problem, which has significantly increased in the conditions of distance and mixed learning. The study of approaches to the effective use of software for the analysis of video recordings of observations of real physical processes and phenomena is one of the tasks of instrumental digital didactics. The affordable and regularly updated software Tracker: Video Analysis and Modeling Tool is a popular didactic tool for the analysis of physical quantities based on the processing of static and dynamic images followed by comparison with the corresponding mathematical model. The rules for creating educational videos suitable for analysis in a digital environment are summarized. On the examples of laboratory classes on many topics of physics (mechanics, hydrodynamics, molecular and atomic physics, and optics) and astronomy, the general features of creating video recordings, laboratory works, and problem tasks based on video analysis are shown. The STEM laboratory of the Junior Academy of Sciences of Ukraine has created numerous reference videos about physical experiments and the rules for their use; a collection of video tasks was also created; innovative methods of educational physical experiments were developed. The methods of video analysis were tested during distance and mixed education in the conditions of threats, also in formal and informal education formats, such as the summer science school for students and the All-Ukrainian natural science online tournament "Open Natural Science Demonstration". Instrumental digital didactics is a component of training courses for teachers and is regularly discussed at seminars and conferences on science education. The stemua.science source of the "MANU" NC is popular among Internet users.

Keywords: video analysis; physics; distance education; distance learning; instrumental digital didactics; Tracker; Junior Academy of Sciences of Ukraine.

1. INTRODUCTION

Statement of the problem. Global crisis situations constantly alert the world pedagogical community regarding didactic innovations in all types of distance learning [1]. A rather difficult problem in this context is the teaching of natural sciences, the empirical basis of which is observation and experiment. The organization and conduct of educational experiments, demonstrations, and laboratory work consist of such basic stages as setting a problem, assembling an experimental setup, conducting an experiment, obtaining data, processing it based on an existing mathematical model, and forming conclusions.

The organization of distance learning of physics at secondary schools and institutions of higher education in the conditions of COVID-19 proved the difficulties of performance (which was obvious) of the first three stages of laboratory work and experiments. The solution to this critical problem in 2020 – 2021 for all natural sciences, as shown by a study of posts on the Internet and our practical experience, was carried out in three main ways.

The most common approach to the organization of laboratory work, the use of which requires only existing software, is a computer simulation of experiments. This approach was used during webinars dedicated to the preparation of educational institutions for distance learning. [2]. It should be noted that the use of modeling in teaching subjects of the natural and mathematical cycle [3], [4], especially for the organization of virtual laboratory works in physics, is popular at all levels of education [5]. Developers offer a variety of online resources with a wide selection of interactive models suitable for conducting virtual experiments. Importantly, many of them are free, such as PhET Interactive Simulations, ComPADRE, VirtuLab, Tinkercad, etc.

Another approach is to create a video recording of the experiment in the laboratory, followed by a remote demonstration. The obtained materials are distributed on distance education platforms of educational institutions or are taught on YouTube channels [6]. Such educational material, as a rule, shows the order of assembling an experimental setup, conducting an experiment, and measuring physical quantities, which students work out independently based on a known mathematical model.

The latest didactic approach is also m-learning, which creates conditions for conducting educational experiments in natural sciences using smartphone sensors [7], [8]. However, this learning method also has limitations: starting with the need for detailed instructions on how to use various sensors, and ending with the difficulties of independent interpretation of the graphic material obtained during the experiment.

Video analysis can be an effective alternative to solving a wide range of educational difficulties in physics that are associated with observing natural processes [9], [10], [11]. The growing attention to the use of such software at various levels of education is confirmed by statistical data on the frequency of use of relevant concepts in scientific reports. The visualization (Fig. 1) shows the number of publications published annually for the combination of keywords «Video Analysis», «Physics», «Distance learning», and «Remote learning». As seen from the graph, the research interest in using video analysis for educational purposes in 2020-2021, which corresponds to the practical developments of 2019-2020, is almost three times higher than in 2015-2016. It is well explained by the demand for the use of such technology in the conditions of distance learning.

Analysis of recent research and publications. The history of using video materials for scientific analysis began with the emergence of photography as a technology. One of the first in this context is the study by E. Muybridge, conducted at the end of the 19th century. His work on the problem of fixation and photographic representation of various types of movement, such as the movement of animals, made a significant contribution to the development of mechanics and biomechanics [12]. His famous successor in the 20th century was H. E. Edgerton, the pioneer of stroboscopic photography [13].

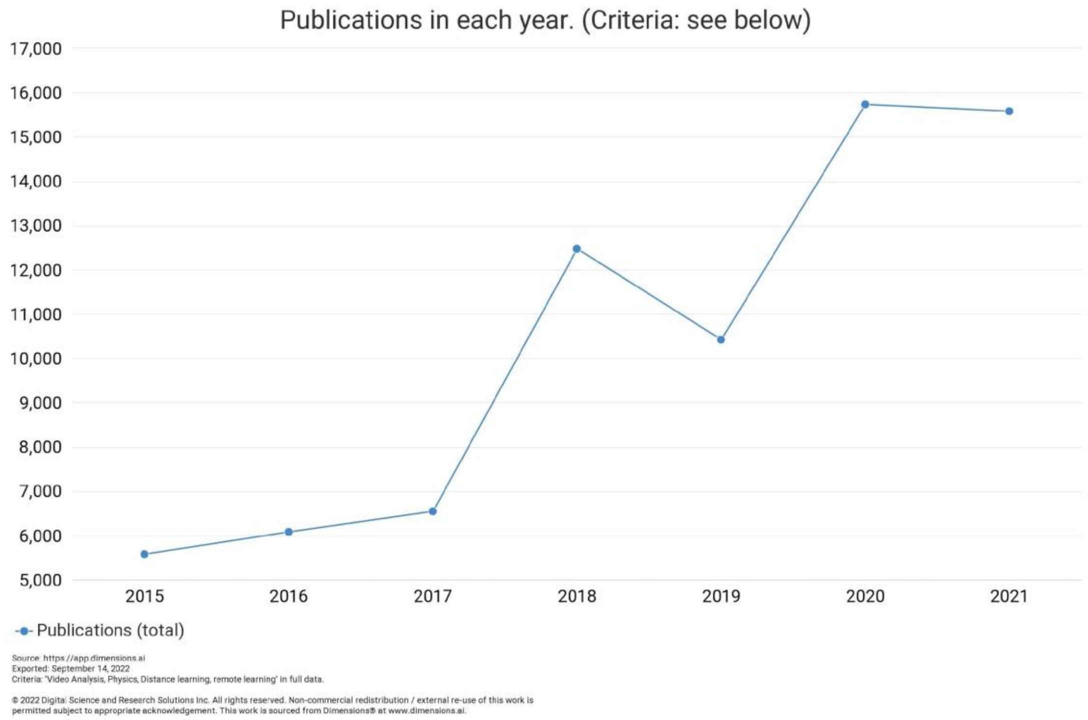

Fig. 1. Data on the annual number of scientific publications by keywords «Video Analysis», «Physics», «Distance learning», and «Remote learning» (www.app.dimensions.ai)

Since their appearance and until now, photo and video data research methods are widely used in all fields of science: biology - for investigation of microorganisms; astronomy – for research of distant galaxies with extraterrestrial telescopes; medicine – to obtain data on the features of the human body (microphotography, magnetic scanning, ultrasound, etc.); history – to analyze photo and video archives; criminology – to obtain photographic evidence, etc.

Now it is difficult to overestimate the role and importance of video analysis in studying physics and other natural sciences. Elements of photography and video are used to study a wide range of phenomena and experiments: from recording mechanical movements to fixing the tracks of elementary particles. Digital technology allows us to determine quickly and accurately the time dependence of the relative position of objects and study the process without interfering with its course.

Video analysis for educational purposes has been widely used since the beginning of the twenty-first century. Combining a full-scale experiment and digital processing of its data, video analysis helps to compare abstract physics concepts with real phenomena and processes «in life»; it can be effectively used in various innovative teaching methods for the development of critical thinking [11]. But, first of all, as noted by A. Artiningsih and S. Nurohman, the use of video analysis during physics study significantly increases the formation of students' research skills [14].

In the era of widespread use of various gadgets, primarily smartphones, participants in the educational process can create videos of phenomena and processes or use a considerable number of online resources – video aggregators for education, such as «The LivePhoto Physics Project» [15].

Analytical processing of video material can be performed using various free or commercial programs, such as Coach Logic [16] or Physics ToolKit [17]. Currently, all well-known training equipment manufacturers, such as Vernier [18], Pasco [19], or Phywe [20], offer video analysis software.

However, the most effective, in our opinion, in terms of exactness and accessibility is the system of video analysis, mathematical and physical modeling – Tracker: Video Analysis and Modeling Tool (hereinafter Tracker). The software is combined with a Web resources network and has significant capabilities. Tracker is a free, multiplatform product that is well-matched with Windows, IoS, and Linux and gives the possibility to import a great number of video file types. It is significant that Tracker is an open source, it is easily updated and improved (now version 6.0.10 is available), and in particular, users can download their own developments to the library [21].

The didactic value of Tracker, which explains its popularity among physics teachers, is the system of tabular and graphical data analysis [22]; it is essential, for example, to eliminate some common misconceptions by comparing personal hypotheses and mathematical models created on the use of videos of a natural process [23]. It is also worth noting that Tracker works with many video file types. Additionally, users can add their videos to the Tracker library.

The tracker is widely used in the world; this is evidenced by numerous pedagogical studies. The subjects that can be studied based on the software can be quite different: from kinematic and dynamic characteristics and physics laws of motion [24, 25, 26] using laboratory instruments, vehicles, and robots [27, 28] to optical phenomena, such as spectral analysis [29]. Tracker also confirmed its effectiveness in developing students' flexible skills [21].

Tracker is an important part of instrumental digital didactics, so its use in the educational process can be part of teacher training programs [30], especially in the context of using the currently popular STEM approach to science education [31].

The research goal. Distance learning of physics and other STEM disciplines based on video analysis requires the development of a significant number of didactic materials on various topics of physics according to existing curricula and individual levels of students’ knowledge and skills. This article highlights the practical experience of creating and using Tracker-based methods for teaching middle and high school students, in formal and informal education settings during distance learning in 2020-2022.

2. RESEARCH METHODOLOGY

Demand for the use of video analysis in distance and blended learning was analyzed using relevant scientific databases (Scopus, Web of Science, Google Scholar, Research Gate, Dimensions). Didactic developments regarding the use of video analysis (on the example of Tracker) were created in the STEM laboratory MAN Lab [31] of the National Center «Junior Academy of Science of Ukraine» (NC JASU); they were tested during distance and mixed training of students in formal and non-formal education in 2020 – 2021, at teacher training courses, seminars, conferences. The evaluation of the visitation of the resource www.stemua.science is based on the data of www.cloudflare.com.

3. RESULTS AND DISCUSSION

In the STEM laboratory MANLab NC JASU, many video experiments have been created for laboratory works in mechanics, molecular physics, optics, and atomic and nuclear physics [37]. At the same time, the following tasks were set:

- the creation of reference videos for performing as many laboratory works as possible according to the formal curriculum;
- development of detailed instructions for data collection and analysis for each laboratory work;

- the creation of "non-traditional" experimental methods adapted for the use of Tracker, which can be used both in formal and informal education, for example, during summer scientific schools;
- the creation of didactic material for the formation of tasks in the format of video problems.

While studying mechanical phenomena using the process record, specific algorithms are used to determine keyframes, shooting frequency, a specific object, and position of the coordinate system. Tracking the position of objects on each frame can be done manually or automatically. Also, there are algorithms for selecting parameters for research, analysis of the graphical or tabular representation of experimental data, construction of a mathematical model corresponding to the studied phenomenon, selection of appropriate coefficients to combine recorded experiment data and the theoretical model.

The main didactic approaches to the use of video analysis have been studied at the STEM laboratory of NC JASU. This is demonstrated by the examples of step-by-step instructions for laboratory works in general physics, which can complement the curriculum in both high school and higher education institutions.

Various didactic approaches can be applied while studying different physics topics. Typically, students are initially asked to conduct an experiment and create a video or use an existing one. This approach allows us to apply the proposed techniques in the full-time, distance, or blended learning.

One of the important mechanics models is the motion of a body thrown at an angle to the horizon. Video analysis for the corresponding experiment extends the classical laboratory work to educational research. The proposed experiment uses a toy spring pistol with a ball, a ruler, a digital camera or a video camera mounted on a tripod, a personal computer, or another gadget (Fig. 2).

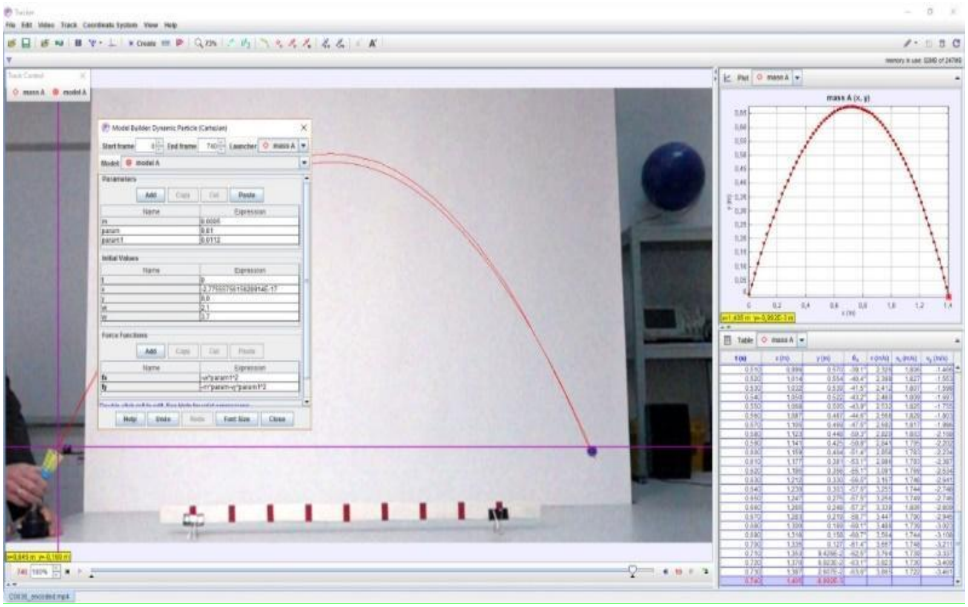

Fig. 2. The view of the Tracker window when creating a mathematical model of the motion of a body thrown at an angle to the horizon

Using Tracker tools, students are asked to perform typical tasks: determine the initial speed of the body, the angle of throw, the distance passed by the ball, and the maximal height of the body flight, as well as explore the nature of the body trajectory. The trajectory of the light ball must be ballistic, and the mathematical model of its motion in the gravitational field will differ from the result of the real experiment. Therefore, an important research task is to create a dynamic model using the option «Model Builder»; based on the model, a conclusion about the specifics of the influence of air resistance can be made (https://cutt.ly/FOd35iL).

A similar method can be used for studying the phenomenon of free fall (https://cutt.ly/QOfySlR). An interesting extension of this work is to find the free-fall acceleration on the Moon. To do this, we use «The Hammer and the Feather» video, which is accessible on the NASA website (https://cutt.ly/OC0do2X) and demonstrates the astronaut Apollo-15 doing the Galileo experiment.

The authors put forward the idea of applying video analysis tools during educational experiments to reveal the peculiarities of the motion of layers of fluid in a whirlpool. The aim is to find the dependence of the speed of the layers on the radius of rotation and the rate of process of the fluid layers on time. A crystallizer with a magnetic stirrer is used to produce a steady whirlpool, and milled coffee - to mark layers of fluid. The webcam is placed parallel to the liquid surface and connected with the laptop that uses the Tracker (Fig. 3).

Fig. 3. Experimental setup for investigation of the speed distribution in the fluid whirlpool

Particles of ground coffee, on the one hand, make the water vortex created by the magnetic stirrer "visible", and on the other hand, they serve as "markers" of the position of the liquid elements (Fig. 4).

Selected areas of fluid are taken in frames, the Tracker video analysis is performed, and the dependence of speed on time for several selected particles is built using the Tracker tools. Also, we can create the experimental dependence of speed on the radius of rotation using the obtained data and the Excel table. It can apply to the forced whirlpool speed distribution model labeled by A.Czubai et al. in [32].

The Tracker is widely applied for mechanical motion study, but the program can be used for experimental data analysis in other fields of physics. An example is a laboratory work «measurement of a liquid surface tension by the method of air bubble formation at a given temperature at a small depth (Rebinder method)» [33].

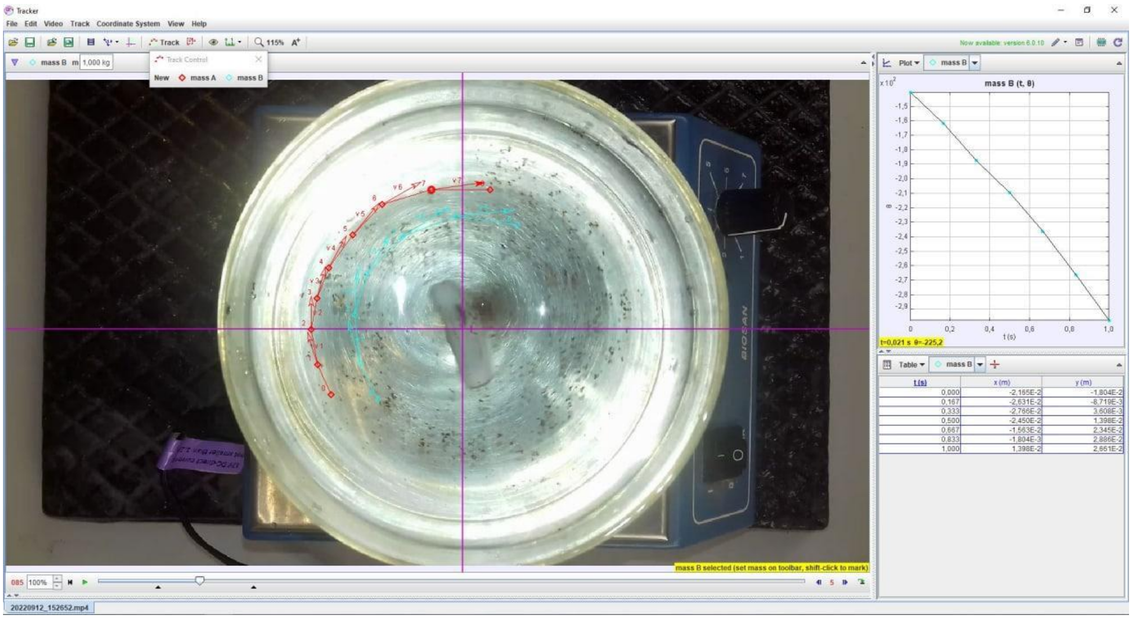

Fig. 4. Artificial whirlpool in water with the Tracker markers of the positions of the fluid elements at different radii of rotation

Condition for air bubbles growth is the appearance of excessive pressure in the bubbles. According to the Laplace pressure model under the curved surface, maximum pressure inside a bubble is at the moment of the bubble creation at the end of the capillary when the bubble diameter is smallest [34].

For the experiment, we have made a device including a container with the test fluid, a glass tube with an extended lower end (capillary), a water aspirator, a beaker, connectors, a three-way valve, silicone tubes, and a water manometer (https://cutt.ly/2Od6PSm).

The fluid has an ambient temperature; the bubbles are formed at the end of a capillary, and its diameter is known or can be found using a microscope. Using the experiment video, Tracker can determine the additional pressure at the time of separation of bubbles (using the liquid manometer); this allows finding the fluid surface tension. (Fig. 5).

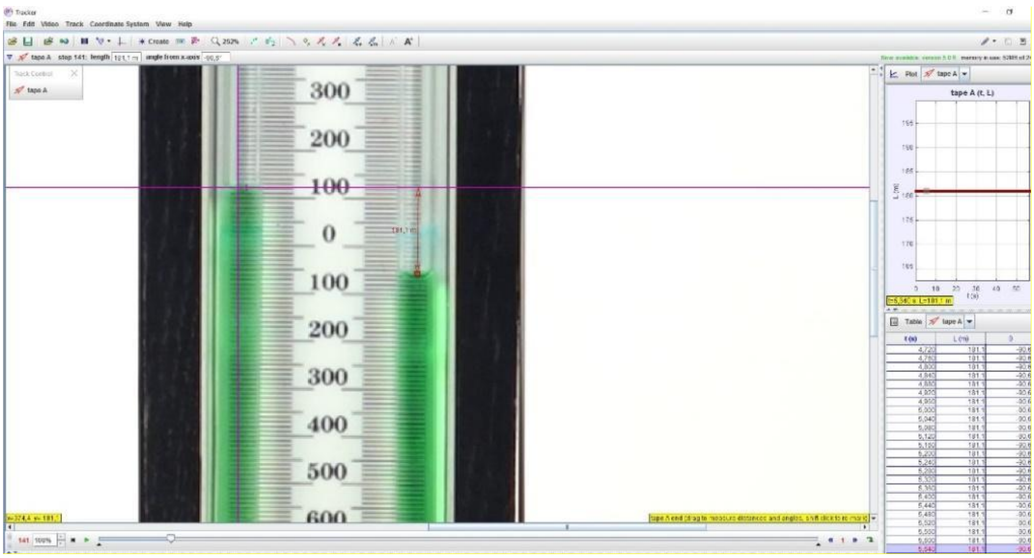

Fig. 5. Tracker program window when measuring the surface tension of the fluid by the Rebinder method

The Tracker's analytical capabilities can also be used for spectral analysis when studying Optics. An example of such an educational study can be the work «Observation of continuous and linear spectra of a substance. Determining the wavelength of light» [35]. For this purpose, the original spectrum images and those available in the Tracker file library can be used. The procedure of this study consists of the following main stages: calibration of the continuous spectrum for two known wavelengths, analysis of light intensity in the linear radiation spectrum, and identification of gas for available wavelength corresponding to the most intense radiation lines (Fig. 6).

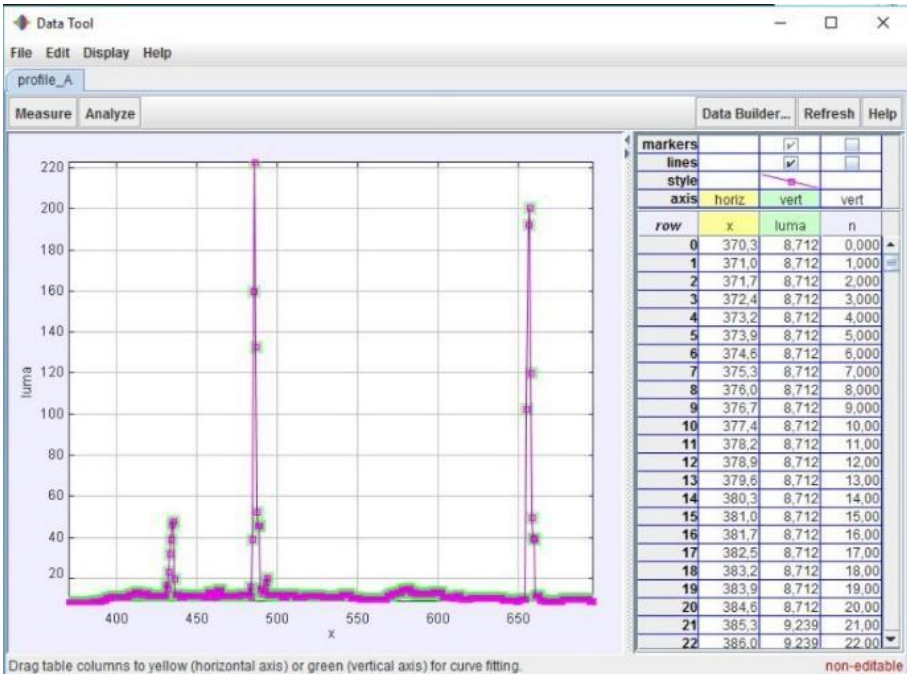

Fig. 6. Distribution of the radiation intensity in the linear spectrum of hydrogen. Screenshot from the Tracker window

The use of video analysis is especially suitable in cases where the laboratory experiment requires special conditions and/or equipment. Consider this for characteristics of radioactive radiation study on the example of laboratory observations of alpha particle tracks. In the proposed method, such a study is performed using photographic and video materials obtained in the laboratory diffusion chamber STEM laboratory MAN Lab (https://cutt.ly/cOfu4hF). This work requires determining the free path length (distance from the radiation source to the beginning of the track) and the length of the track itself, which characterize the particle energy. Tracker tools for measuring linear lengths are calibrated with the specified needle magnitude of the radioactive source, after which we can measure the distance from the source to the beginning of the alpha particle track (Fig. 7).

Based on the results of measuring the free path length for each photo or video material frame, students are asked to determine the arithmetic mean of these values and make a conclusion about the energy of alpha particles [46].

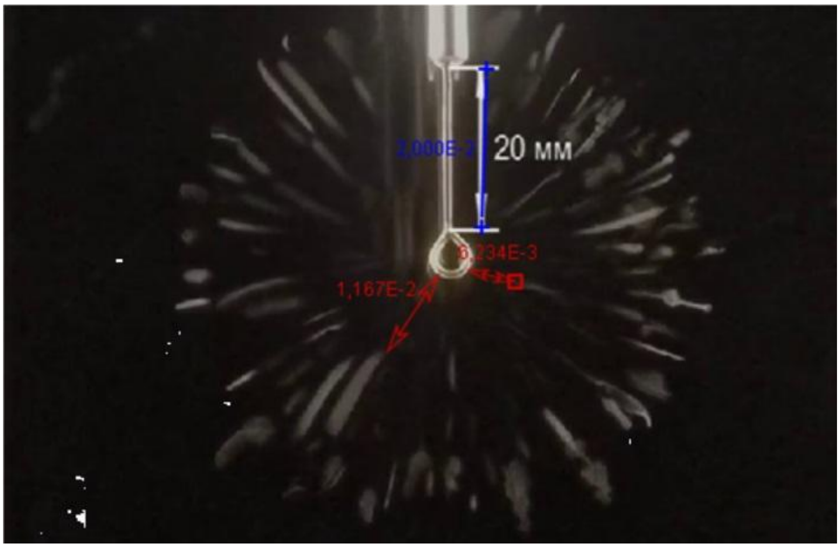

Fig. 7. Measuring the free path length of alpha particles with Tracker tools

Video analysis is important for studying the characteristics of astronomical objects. An interesting didactic application of video analysis in the context of astrophysics is the study of the rotational motion of the Sun based on images of the visible motion of its photosphere. The objects of observation in this case are sunspots. A video image of the Sun surface (Fig. 8) obtained by the SOHO Space Observatory over a long period of time can be used for the analysis (https://sohowww.nascom.nasa.gov/).

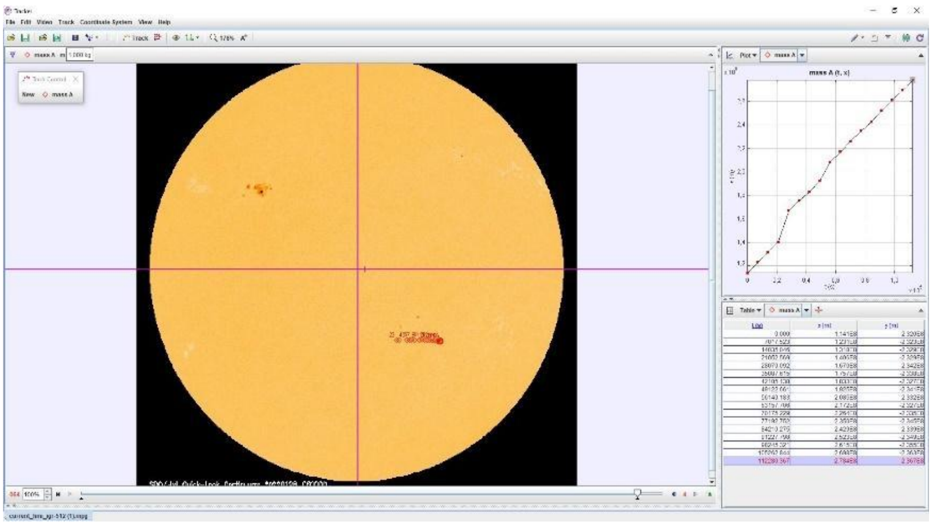

Fig. 8. Video analysis of the motion of the photosphere of the Sun. Tracker window

A model of a circular uniform motion can be used to describe the motion of sunspots. Using the Tracker tools, a graphical dependence on time is constructed on a known linear coordinate, which is approximated by a straight line. The coefficient adjoining t corresponds to the value of the linear velocity of the spot (Fig. 9). The procedure is repeated for several sunspots. The solar latitude is determined for each of them with the help of a virtual conveyor. Thus, using the Tracker analytical tools, we can find, for example, the speed of the photosphere and the period of rotation of the Sun at different latitudes (https://cutt.ly/FOfkbF1).

Fig. 9. Determination of the linear velocity of the sunspot: approximation of experimental results in Tracker window

The created video tasks were tested during distance and mixed learning in formal education, as well as during various extracurricular educational activities for students and teachers in Ukraine. We received confirmation of the effectiveness of the use of video analysis tools for training motivated, capable youth during summer scientific schools under the patronage of NC JASU. The evaluation of the works showed that the majority of the event participants can use the Tracker toolkit at a sufficient level [36].

Thus, a significant number of high school students are technically competent and willing to use video analysis tools to study physical phenomena according to instructions. But only 3% of students confirmed their abilities at the creative level.

The All-Ukrainian Online Olympiad in Natural Science "Open Natural Demonstration" (https://vpd.stemua.science/), which took place in October – November 2021, was an additional opportunity to check laboratory work using video analysis. More than 2,000 students from Ukraine became its participants. In the selection round of this competition, among 20 tasks, a video task was offered to determine the coefficient of sliding friction based on a video analysis of the movement of a body on an inclined plane, which was successfully completed by 80% of the participants. A detailed analysis of the solutions provided by the teams showed, first of all, that the students have good skills in working with software tools. At the same time, the main problem was the comparison of the obtained results with the mathematical model of the considered phenomenon and the explanation of the differences between them. Studies of the effectiveness of using video analysis in the All-Ukrainian Online Olympiad in Natural Science "Open Natural Demonstration" are ongoing. In 2022, at the Olympiad selection stage, the participants were offered a video task using the Tracker to measure angles and distances to find component forces.

Methodical work on the creation of didactic materials based on video analysis has been going on for more than 10 years in the STEM laboratory of the Junior Academy of Sciences of Ukraine. During this time, 40 different methods of performing laboratory work have been created, video materials and video lectures have been prepared, which were tested during formal and informal education in secondary and higher schools, especially intensively – during distance learning in conditions of threats. The received didactic materials and developments are presented on the free access resource stemua.science in the "Instrumental digital didactics" section. Studying the statistics of its visits with the help of www.cloudflare.com shows a significant interest in the video analysis methods created and tested by us, not only in the Ukrainian, but also in the world community of teachers (Fig. 10).

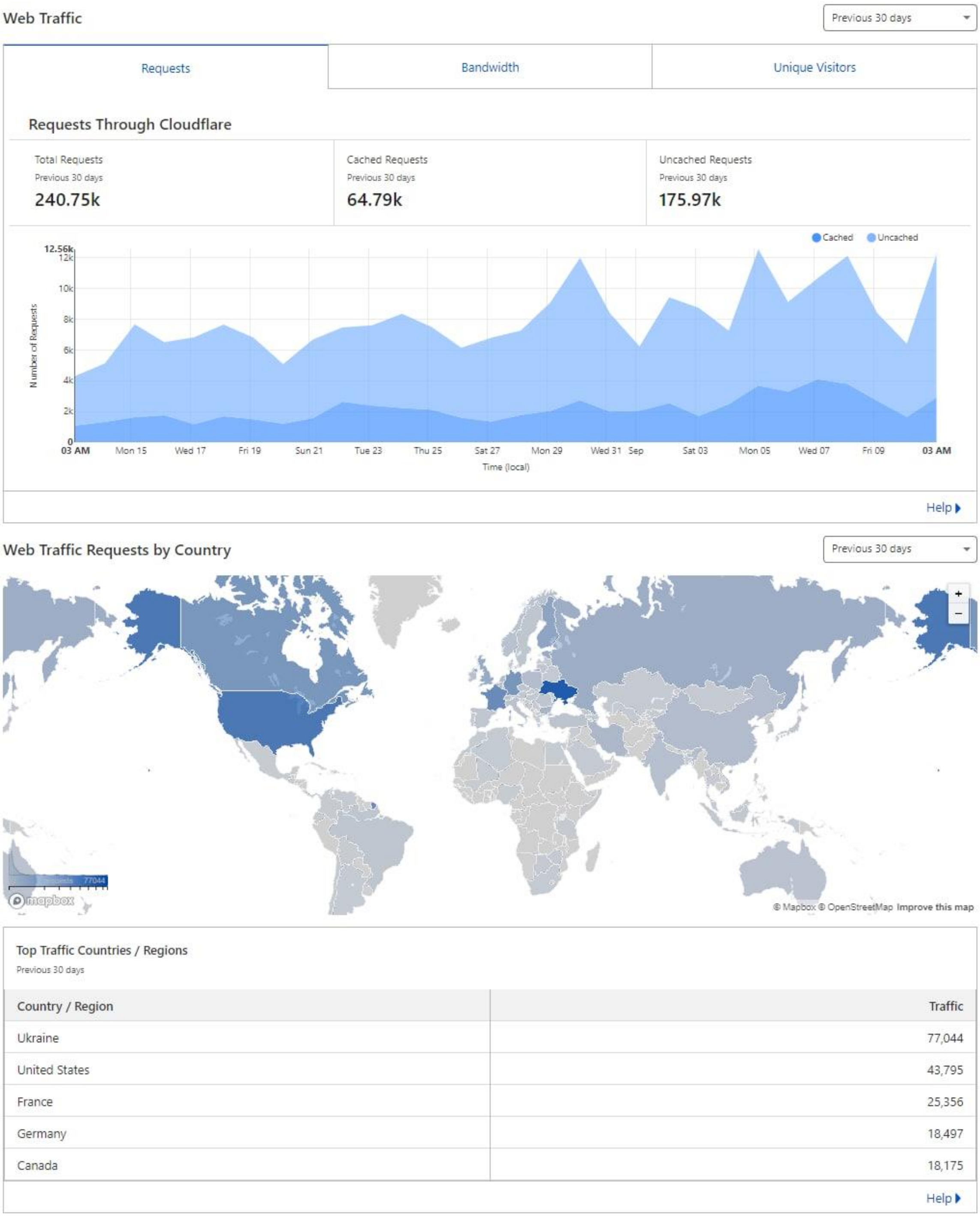

Fig. 10. Web Traffic stemua.science requests by Country (top); the total number of visits during August-September 2022 (below); (according to www.cloudflare.com)

4. CONCLUSIONS

The result of the study is the adaptation of the Tracker software for distance and blended learning. The samples of video analysis using the Tracker described in the article were widely used during the study of physics by students at the Junior Academy of Sciences of Ukraine. The manual "Instrumental digital didactics" was developed, which summarizes the main theoretical principles and techniques of using Tracker Video Analysis [37]. During the work, a set of video tasks for the Tracker was made. A high-quality video archive has been created due to the high frequency of used recordings. It can be seen in the section "Supplementary materials" [31]. In addition, Tracker resources contain educational data suitable for entry-level projects.

The methodology was used as a supplement during the study of physics in secondary schools and in teacher training courses. These methods have been tested at the National Aviation University and Kherson State University. It should also be emphasized that performing video analysis tasks with the help of Tracker stimulates students to independently create similar videos. This is confirmed by the active participation of students of Kherson State University in the "Week of Science" contest for the best video experiment and video puzzle.

Our further didactic research will be aimed at expanding the practice of studying physics, achieving the level of ingenuity in using video analysis. Our aim is to enable students who learn to work with the Tracker system to independently conduct experiments or use the resources available in the library.

REFERENCES (TRANSLATED AND TRANSLITERATED)

[1] N. I. Polikhun, O. M.Vilchynska, I. A.Slipukhina, & K. H. Postova, "Effectiveness Of Distance Learning During Covid-19 Pandemic From Educational Process Participants' Viewpoint", *Information Technologies and Learning Tools*, vol. 86, no. 6, pp. 357–372, 2021; doi: https://doi.org/10.33407/itlt.v86i6.4617. (in English).

[2] Distance Learning: Organization of Laboratory and Practical Works. Institute of Information Technologies and Learning Tools National Academy of Pedagogical Sciences of Ukraine. (n.d.); [Online]. Available: https://iitlt.gov.ua/info/news/sem-nari/dystantsiyne-navchannya-organizatsiya-laboratornykh-i-praktychnykh-robit/ (in Ukrainian).

[3] S. Lytvynova, "The Model of The Use of Computer Modeling System for Formation Competences of Natural and Mathematical Subject Students", *Physical and Mathematical Education*, vol. 19, no. 1, pp. 108–115, 2019; doi: https://doi.org/10.31110/2413-1571-2019-019-1-017 (in Ukrainian).

[4] N. P. Dementiievska, O. P. Pinchuk, O. V. Slobodianyk, O.M. Sokoliuk, "Osoblyvosti vykorystannia kompiuternykh modeliuvan u shkilnomu kursi fizyky", *Informatsiino-tsyfrovyi osvitnii prostir Ukrainy: transformatsiini protsesy i perspektyvy rozvytku*: zbirnyk naukovykh prats / [kolektyv avtoriv] [Peculiarities of using computer simulations in the school physics course. Information and digital educational space of Ukraine: transformational processes and development prospects: a collection of scientific works / [collective authors]]; Za red. V.H. Kremenia, O.I. Liashenka; ukl. A.V. Yatsyshyn, O.M. Sokoliuk. K.: 361 s. pp.67-79, 2019. [Online]. Available:https://lib.iitta.gov.ua/id/eprint/718707 (in Ukrainian).

[5] I. Slipukhina, S. Kuzmenkov, N. Kurilenko, S. Mieniailov, H. Sundenko, "Virtual educational physics experiment as a means of formation of the scientific worldview of the pupils": *ICT in Education, Research, and Industrial Applications*. 15 th Int. Conf. ICTERI 2019. Volume I: Main Conference. 2019, pp. 318-333, CEURWS.org, [Online]. Available: http://ceur-ws.org/Vol-2387/. (in English)

[6] P. Victor, Blog on physics. [Online]. Available: https://www.youtube.com/channel/UCWfhBu4fAt126ZbxREz3IBw (in Ukrainian)

[7] T. J. Kilty, A. C. Burrows, "Systematic Review of Outdoor Science Learning Activities with the Integration of Mobile Devices", *International Journal of Mobile and Blended Learning*, vol.12, no. 2, pp.. 33–56, 2020; doi: https://doi.org/10.4018/ijmbl.2020040103. (in English)

[8] I. Slipukhina, I. Chernetckiy, N. Kurylenko, S. Mieniailov, & S.Podlasov, "Instrumental Digital Didactics of physics study in the aspect of M-learning", *Information and Communication Technologies in Education, Research, and Industrial Applications*, 2021, pp.3–21.; doi:https://doi.org/10.1007/978-3-030-77592-6_1. (in English).

[9] G. Tarantino, C. Fazio, "Video analysis of the flight of a model aircraft". *European Journal of Physics*, 32(6), pp.1617–1623, 2011; doi: https://doi.org/10.1088/0143-0807/32/6/015. (in English)

[10] L. Kang Wee, & T.Kwang Leong, "Video analysis and modeling performance task to promote becoming like scientists in classrooms". *American Journal of Educational Research*, 3(2), 197–207. 2015; doi: https://doi.org/10.12691/education-3-2-13. (in English).

[11] R. Allain, Detecting fake videos. Physics and Video Analysis. 2016 doi: https://doi.org/10.1088/978-1-6817-4067-6ch7. (in English).
[12] Muybridge, Eadweard (1830–1904). Oxford Dictionary of National Biography. 2018; doi: https://doi.org/10.1093/odnb/9780192683120.013.35174. (in English).
[13] Harold «Doc» Edgerton. Harold 'Doc' Edgerton, visionary engineer. The Edgerton Digital Collections (EDC) project. (n.d.). [Online]. Available: http://edgerton-digital-collections.org/. (in English)
[14] A. Artiningsih, S. Nurohman, “Analysis of investigative skills based on the use of tracker video analysis for 21th century skill”, *Journal of Science Education Research*, 2020, doi: 3. 10.21831/jser.v3i2.30621 (in English).
[15] LivePhoto Physics Project. (n.d.). [Online]. Available: https://www.rit.edu/cos/livephoto/ (in English)
[16] Collaborative Video Analysis Software for Sports Teams. Coach Logic. (2021, January 8). [Online]. Available: https://www.coach-logic.com/ (in English)
[17] Physics ToolKit. (n.d.) [Online]. Available: http://ptk60.com/ (in English)
[18] Logger Pro® 3. Vernier. (n.d.). [Online]. Available: https://www.vernier.com/product/logger-pro-3/ (in English)
[19] Science Lab Equipment and Teacher Resources. PASCO scientific. (n.d.). [Online]. Available: https://www.pasco.com/. (in English)
[20] Phywe.de. (n.d.). [Online]. Available: https://www.phywe.com/ (in English)
[21] Tracker Video Analysis and Modeling Tool for Physics Education. (n.d.). [Online]. Available: https://www.physlets.org/tracker/
[22] D. Brown, A. J. Cox, “Innovative Uses of Video Analysis”, *The Physics Teacher*, 47(3), 145–150, 2009; doi:10.1119/1.3081296 . (in English)
[23] D.Muliyati, A. D.Septiningrum, D.Ambarwulan, , & I. M. Astra, “The development of Guided Inquiry Student Worksheet using tracker video analysis for kinematics motion topics”, *Journal of Physics: Conference Series*, vol. 1491, no. 1, p.012062. 2020; doi: https://doi.org/10.1088/1742-6596/1491/1/012062. (in English)
[24] O. S Sastri, K. S. Swathi, Deepa, S., & S.Sharma, “Video analysis of double pendulum using tracker”. *Journal of Research: The Bede Athenaeum*, vol. 12, no. 1, pp.33–422021. doi: https://doi.org/10.5958/0976-1748.2021.00004.7. (in English)
[25] S. Utari, E. C.Prima, “Analisis Hukum Kekekalan Momentum Model tumbukan Kelereng Dengan Gantungan ganda menggunakan analisis video tracker”, *Jurnal Pendidikan Fisika Dan Keilmuan (JPFK)*, vol.5, no. 2, p.83. 2019; doi: https://doi.org/10.25273/jpfk.v5i2.4145. (in English)
[26] M. Syepudin, R.Badriah, R.Warga, T.Kartini, W.Zikbal, “Menganalisis sudut pendulum pada bidang miring menggunakan software tracker video”. *JoTaLP: Journal of Teaching and Learning Physics*, 3, 2, 2018: 14-20 Website: http://journal.uinsgd.ac.id/index.php/jtlp/index ISSN 2580-3107 (online) ISSN 2528-5505. doi:http://dx.doi.org/10.15575/jtlp.v3i2.6553 (in English)
[27] H. Ramli, K. T. Chan, Y. W. Fen, “Study Of Simple Pendulum Using Tracker Video Analysis And High Speed Camera: An Interactive Approach To Analyze Oscillatory Motion”, *Solid State Science and Technology*. vol. 24. pp. 297-305, 2016 (in English)
[28] P. W.Laws, R. B Teese, D. P.Jackson, M. C.Willis, & K.Koenig, “Using online interactive physics-based video analysis exercises to enhance learning”, *Scientia in Educatione*, 8. 2017; doi: https://doi.org/10.14712/18047106.747 (in English)
[29] A. Asrizal, Y. Yohandri, Z. Kamus, “Studi Hasil Pelatihan Analisis Video dan tool pemodelan tracker pada guru MGMP Fisika Kabupaten Agam”, *Jurnal eksakta pendidikan (JEP)*, 2(1), 41, 2018; doi: https://doi.org/10.24036/jep/vol2-iss1/84 (in English)
[30] Y. Shapovalov, R.Tarasenko, S.Usenko, V.Shapovalov, F. Andruszkiewicz, A.Dolhanczuk-Sródka, “Ontological Information System for the selection of technologies for the treatment and disposal of organic waste: Engineering and educational aspects”, *Desalination and water treatment*, vol. 236, pp. 226–239, 2021; doi: https://doi.org/10.5004/dwt.2021.27689. (in English).
[31] STEM-laboratoriia MANLab [STEM-laboratory MANLab]. [Online]. Available:http://stemua.science (accessed 26.01.2021) (in Ukrainian)
[32] A. Czubai, N. Sopko, A. Patel, H. Ahmari, S. Kabir, “Experiment #8: Free and forced vortices. Applied Fluid Mechanics Lab Manual”, [Online]. Available:https://uta.pressbooks.pub/appliedfluidmechanics/chapter/experiment-8/ Retrieved January 29, 2022, 2019 (in English).
[33] M. Korenko, F. Šimko, “Measurement of interfacial tension in liquid−liquid high-temperature systems”, *Journal of Chemical & Engineering Data*, 55(11), 4561–4573, 2010. doi: https://doi.org/10.1021/je1004752. (in English).
[34] R. Chen, L. Zhang, D. Zang, W. Shen, «Wetting and Drying of Colloidal Droplets: Physics and Pattern Formation». *Advances in Colloid Science*. 2016 doi: https://doi.org/10.5772/65301 (in English)
[35] C. Mori «Visibility of the growth direction of an alpha-particle track in a diffusion cloud chamber». *Journal of Nuclear Science and Technology*, 51(2), 196–200, 2013; doi: https://doi.org/10.1080/00223131.2014.854710. (in English)

[36] I. Chernetskyi, I. Slipukhina, N. Kurylenko, S. Mieniailov, M. Opachko. «The Application of Tracker Video Analysis for Distance Learning of Physics». *CEUR Workshop Proceedings*, 3013:182–92. 2021.[Online]. Available:http://icteri.org/icteri-2021/proceedings/volume-1/20210182.pdf (in English)
[37] Physics. Applied methods of instrumental digital didactics: a textbook (2020). [Online]. Available: http://man.gov.ua/files/49/Physics.pdf (in Ukrainian)

Text of the article was accepted by Editorial Team 14.09.2022

МЕТОДИ ДИСТАНЦІЙНОЇ ОСВІТИ: ВІДЕОАНАЛІЗ У НАВЧАННІ ФІЗИКИ

Чернецький Ігор Станіславович
кандидат педагогічних наук, завідувач відділу створення навчально-тематичних систем знань
Національний центр «Мала академія наук України», м. Київ, Україна
ORCID ID 0000-0001-9771-7830
manlabkiev@gmail.com

Сліпухіна Ірина Андріївна
доктор педагогічних наук, професор, головна наукова співробітниця
Національний центр «Мала академія наук України», м. Київ, Україна
ORCID ID 0000-0002-9253-8021
slipukhina2015@gmail.com

Мєняйлов Сергій Миколайович
кандидат педагогічних наук, доцент, доцент кафедри загальної та прикладної фізики
Національний авіаційний університет, м. Київ, Україна
ORCID ID 0000-0002-4871-311X
msm56msm@gmail.com

Куриленко Наталія Валентинівна
кандидат педагогічних наук, викладачка кафедри фізики і астрономії
Херсонський державний університет, м. Херсон, Україна
ORCID ID 0000-0002-1083-3247
kurylenko.n.v1976@gmail.com

Анотація. Формування навичок проведення експерименту та аналізу його результатів під час проведення лабораторних робіт з природознавства завжди було важливою дидактичною проблемою, яка значно посилилась в умовах дистанційного та змішаного навчання. Дослідження підходів до ефективного використання програмного забезпечення для аналізу відеозаписів спостережень реальних фізичних процесів і явищ є одним із завдань інструментальної цифрової дидактики. Доступне та регулярно оновлюване програмне забезпечення Tracker: Video Analysis and Modeling Tool є популярним дидактичним засобом для аналізу фізичних величин на основі обробки статичних і динамічних зображень з наступним порівнянням з відповідною математичною моделлю. Узагальнено правила створення навчальних відео, придатних для аналізу в цифровому середовищі. На прикладах лабораторних занять з багатьох тем фізики (механіки, гідродинаміки, молекулярної та атомної фізики, оптики) та астрономії показано загальні особливості створення відеозаписів, лабораторних робіт, проблемних завдань на основі відеоаналізу. STEM-лабораторією Малої академії наук України створено численні довідкові відео про фізичні експерименти та правила їх використання; також створено збірник відеозавдань; розроблено інноваційні методики навчального фізичного експерименту. Методи відеоаналізу апробовано під час дистанційного та змішаного навчання учнів та студентів в умовах загроз, під час формального та неформального навчання: літньої наукової школи для студентів, Всеукраїнського природничого онлайн-турніру «Відкрита природнича демонстрація» . Інструментальна цифрова дидактика є компонентом курсів підготовки вчителів і регулярно обговорюється на семінарах і конференціях з наукової освіти. Джерело stemua.science НЦ «МАНУ» користується популярністю серед користувачів мережі Інтернет.

Ключові слова: відеоаналіз; фізика; дистанційна освіта; дистанційне навчання; інструментальна цифрова дидактика; Tracker; Мала академія наук України.