The object of this study is the wear resistance of marks for people with visual impairments, which are printed by the intaglio printing method on Ukrainian hryvnia banknotes to identify the banknote denominations. The subject of the study is to determine the impact of wear on the recognizability of marks for people with visual impairments and the identification of banknote denominations by people with visual impairments. The paper considers the problem of inadequate assessment of the level of banknote wear by the systems of control and rejection of protected products from the point of view of banknote accessibility for people with visual impairments.

An improved methodology for determining the level of wear of the mark for people with visual impairments on Ukrainian hryvnia banknotes is given, taking into account the indicator of its accessibility for all population groups, in particular for people with absolute vision loss, throughout the entire period of circulation. According to the developed methodology, artificial wear of banknotes was carried out according to three test options. The results of changes in the mass of banknotes, the microstructure of the surface of banknotes, the compressibility of marks for people with visual impairments (elasticity level), and the level of tactile identification of the denomination of banknotes by people with total vision loss were obtained. It was determined that during the artificial wear of banknotes, the main destruction of the mark takes place in the first cycle. After the second cycle of wear, there is an increase in the elasticity of the mark for people with visual impairments, a decrease in the level of its tactile sensation and the identification of the denomination of the banknote. Therefore, the properties of banknotes after the second cycle of wear have been determined to be critical for withdrawing such banknotes from circulation.

The revealed regularities make it possible to adjust the parameters of intaglio printing during the production of banknotes and to adjust the sorting equipment to determine the suitability of banknotes for further circulation, taking into account the criterion of accessibility of banknotes for all groups of people

Keywords: mark for people with visual impairments, wear of banknotes, denomination identification, Ukrainian hryvnia

UDC 655.3.06
DOI: 10.15587/1729-4061.2023.287746

IMPROVING A METHOD FOR DETERMINING THE LEVEL OF WEAR OF THE MARK FOR PEOPLE WITH VISUAL IMPAIRMENTS ON UKRAINIAN HRYVNIA BANKNOTES

Tetiana Kyrychok
Doctor of Technical Sciences, Professor
Department of Printing and Publishing Technologies*
Olena Korotenko
Corresponding author
PhD, Associate Professor
Department of Printing and Publishing Technologies*
E-mail: gushcha.olena@gmail.com
Yaroslav Talimonov
Postgraduate Student
Department of Printing and Publishing Technologies*
Andrii Kyrychok
PhD, Associate Professor
Department of Publishing and Editing*
*Publishing and Printing Institute
National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»
Anhelia str., 1/37, Kyiv, Ukraine, 03056

Received date 11.07.2023
Accepted date 18.09.2023
Published date 30.10.2023

How to Cite: *Kyrychok, T., Korotenko, O., Talimonov, Y., Kyrychok, A. (2023). Improving a method for determining the level of wear of the mark for people with visual impairments on Ukrainian hryvnia banknotes. Eastern-European Journal of Enterprise Technologies, 5 (1 (125)), 92–103. doi: https://doi.org/10.15587/1729-4061.2023.287746*

1. Introduction

At least 2.2 billion people worldwide are visually impaired [1]. To overcome the problem of the complexity of perception of the surrounding environment and many everyday and social activities by visually impaired people, it is necessary to use as many technological and organizational means as possible. One of the most important problems faced by blind and visually impaired people is identifying and locating various objects in space, including recognizing banknote denominations. Therefore, the ability to identify banknote denominations by visually impaired people is one of the main requirements for modern currency marks.

The task to ensure the inclusion of people with vision problems is also relevant for the production of banknotes of the Ukrainian currency – the hryvnia. In the production of hryvnias, the specified problem is solved by applying a number of measures, the main of which are:

1) production of banknotes of different denominations, different in size and color;

2) putting special tactilely recognizable elements on them – marks for people with visual impairments (MPVI). The main method for applying MPVI on banknotes is intaglio printing (metallographic printing), the main feature of which is the possibility of forming strokes with different thicknesses of the ink layer.

The quality of banknote products is determined by the indicators of security, recognizability, machine readability, aesthetic perception, and manufacturability, which should be inherent in banknotes throughout the time they are in circulation.

However, during the life cycle, banknotes are exposed to many environmental factors, such as moisture, sebaceous secretions of hands, frictional mechanisms of counting and sorting equipment, various clamps, household dirt in various combinations, bending and crumpling, and friction. As a result, this leads to wear of the banknotes, and, accordingly, to a decrease in the overall quality of the banknotes. This process, in turn, negatively affects the identification of the authenticity of banknotes in society, including the identification of banknote denominations by people with visual impairments.

2. Literature review and problem statement

Papers [2, 3] describe the main elements of highly protected products, which allow all groups of the population, in particular people with visual impairments, to identify the denomination of banknotes and the authenticity of protected products. A special role among such elements is played by relief, tactilely recognizable design elements – MPVI, applied by intaglio printing and/or colorless embossing, and high contrast of the printed background and the image to be identified. However, the cited studies did not investigate the impact of banknote wear on the denomination and authenticity identification process using these elements. Accordingly, it is not known for certain whether these elements work as a means of identification of the denomination by people with visual impairments in the process of banknote circulation.

There are various automatic banknote denomination recognition systems that can be used both by sorting machines and by people with visual impairments in everyday life. In particular, papers [4, 5] report various techniques for banknote denomination identification, which are based on image processing using neural networks by analyzing and comparing incoming banknotes with a certain reference image and its characteristics. Similar methods are included in the work of sorting equipment and various mobile applications for identifying the denomination and authenticity of banknotes. However, they require high-tech and expensive solutions. In particular, high-quality cameras are needed, capable of capturing different shades of banknotes, distinguishing elements of wear (crumples, dirt, abrasions, tears, etc.) from elements of banknote design, perceiving banknote elements under different lighting conditions. Study [6] proposed a system for automated recognition of the country of origin using certain predefined areas of the banknote, and using characteristics such as size, color, or text on the banknote, recognition of the denomination of the banknote. The result can be provided in the format of the graphical user interface, as well as in the audio format. This method also requires the use of additional devices for input, processing, and output of results, which prevents its wide application. Paper [7] reports the research conducted in four main areas in the field of accurate banknote recognition using various sensors in automated banknote processing machines. However, the work does not give the results of recognition of worn banknotes by automated sensors and does not take into account the real experience of identifying denominations by people with visual impairments, including people with complete vision loss.

All of the above methods [4–7] require an appropriate level of knowledge to configure the equipment for a specific banknote. The limitation of such devices and the lack of highly qualified personnel in institutions that perform sorting, control, and rejection of protected products can lead to the return of products with low quality indicators into circulation. This reduces the level of security and the possibility of identification of the denomination by people with visual impairments and negatively affects both the economy and security of the state, as well as the level of inclusiveness in society.

Banknote denomination recognition methods based on image processing also inadequately take into account the physical changes of banknotes during their circulation. In particular, it is quite difficult to assess the preservation of the tactility of banknotes, which is the main tool for identifying both the authenticity and the denomination of a banknote by people with visual impairments in everyday life. An option to overcome the relevant difficulties may be the preliminary withdrawal of banknotes of a certain level of wear, which cannot be identified by people with visual impairments. To this end, banknotes need to be subjected to degradation under conditions close to the conditions of actual circulation, and by measuring the corresponding wear indicators at various stages, to determine their level of suitability for further use.

Paper [8] provides a method of banknote degradation that simulates the effects that occur during real circulation, such as destruction of the structure, loosening and tearing of the edges, crumpling, contamination, etc. However, this method has a significant drawback from the point of view of MPVI research: to prevent twisting of the banknote, special synthetic tapes are placed on its side surfaces (in width), which are fixed by special weighting holders. The locations of these tapes with holders are traditionally such that they completely cover the examined MPVI, which causes insufficient and inadequate degradation of these areas of the banknote in the simulator, which is not adequate to the actual conditions of circulation. In works [9, 10], the use of a contaminating mixture of a certain composition was proposed, which most closely simulated the external effects on banknotes. But the issue of using black pigment to simulate pollution remains unresolved, which may distort the results of the study specifically for people with visual impairments.

An option to overcome these difficulties may be to involve people with visual impairments in testing samples of different levels of wear, obtained by methods of artificial degradation. There are procedures [11] for studying the tactility of prints by different groups of people but they need to be improved in view of the need to identify the authenticity of banknotes and accurately determine the denomination of banknotes by people with impaired vision.

All this allows us to assert that the improvement of the methodology for assessing the level of wear of banknote products, taking into account the indicator of its accessibility for people with visual impairments throughout the entire period of circulation, is an urgent scientific and technical task of national importance. In order to confirm the effectiveness of the methodology, it is advisable to conduct relevant studies related to it.

3. The aim and objectives of the study

The aim of our work is to improve the methodology for assessing the wear of MPVI on Ukrainian hryvnia banknotes, taking into account the criterion of banknote accessibility for all population groups, in particular for people with visual impairments. This will make it possible to adjust the parameters of intaglio printing during the production of banknotes and to adjust the sorting equipment to determine the suitability of banknotes for further circulation.

To achieve the goal, the following tasks were set:

– to propose an algorithm for the procedure of determining the impact of the level of wear of banknotes on the accessibility of banknotes for people with visual impairments;

– to conduct a study into the effect of the level of wear of banknotes on the characteristics of banknotes: to study the influence of the level of wear of banknotes on changes in the mass of banknotes, to investigate changes in the ability of the mark for people with visual impairments to compress when banknotes are worn, to examine changes in the microstructure and relief of the surface of the mark for people with visual impairments during the wear of banknotes;

– to conduct a study into the influence of the level of wear on the identification of banknote denominations by people with visual impairments.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of this study is the wear resistance of marks for people with visual impairments, which are printed by the intaglio printing method on Ukrainian hryvnia banknotes to identify the banknote denominations. The subject of the study is to determine the impact of wear on the recognizability of marks for people with visual impairments and the identification of banknote denominations by people with visual impairments. The main hypothesis of the study assumes that when banknotes reach a certain level of wear, they may become unusable from the point of view of accessibility for people with visual impairments. The study is aimed at solving the problem of inadequate assessment of the level of wear of banknotes by the systems of control and rejection of protected products from the point of view of accessibility of banknotes for people with visual impairments.

4. 2. Methods of experimental studies into the influence of the level of wear of banknotes on changes in the characteristics of banknotes

4. 2. 1. Devices and materials

Research was conducted with samples of banknotes with a denomination of 20 hryvnias in the amount of 90 pcs. Artificial wear of banknote samples was carried out in a banknote circulation simulator [8–10].

The samples of banknotes were rotated in a wear simulator in the environment of glass balls with a diameter of 3–5 mm, total weight – 2000 (+/–10) g, 62 coins with a denomination of 1 kop. with a total weight of 95 (+/–10) g, and a polluting mixture (synthetic dirt), the composition of which is given in Table 1. In contrast to the procedures in [8, 10], the composition of the polluting mixture did not contain black pigment to avoid distortion of the results of perception of MPVI by people with impaired vision.

Table 1

Composition of the pollutant mixture

Component	Percentage of mass
Red cosmetic clay	16 %
Sunflower oil	28 %
Lanolin	28 %
Ethyl alcohol	28 %

At the edge of the banknote, four plastic bands with a thickness of 0.5 mm were previously inserted with four fluoroplastic fasteners. The introduction of tapes takes place along the short edges of the banknote on the front and back sides in order to provide additional rigidity and prevent the banknotes from twisting in the environment of wearing agents inside the circulation simulator. The fasteners are four pairs of «screw-nuts» with a head diameter of 16 mm, a length of 20 m, and a weight of 9.3 (+/–0.2) g each, which fix the tapes and additionally act as loaders. In order to eliminate the obstacle to the wear of MPVI and their further examination, the tapes with fasteners were moved to a certain distance from the edge of the banknote (Fig. 1).

The wear simulator worked under an automatic mode. During every 30 min. the drum of the simulator twice changed the direction of rotation to the opposite.

4. 2. 2. Procedure for determining a change in the weight of banknotes

A change in the mass of banknotes m_i^k (k=[0,3], the number of completed cycles, i=[1,90], the serial number of the sample) after processing them in the wear simulator became one of the main indicators of wear. This indicator confirms the accumulation of a contaminating mixture by the base of the banknote and is expressed in the average value of the increase in the mass of the banknotes $\overline{m}_{ni}^k$, and the amount of accumulated dirt during a cycle M_{ni}^k, n is the number of examined banknotes.

The mass of banknotes was measured after each stage of the study; the results of measurements of changes in the mass of banknotes were recorded and entered in the appropriate tables.

4. 2. 3. Procedure for determining a change in the capability of a mark for people with visual impairments to compression

The tests were carried out using a thickness gauge with a test pin with a diameter of 3 mm. The pressure on the test mark was 17.1 g per 1 mm^2. The change in the height of the mark for people with visual impairments on banknotes was measured under a kinetic mode with a discreteness of 10 s.

The tests were carried out both on new banknotes and after each cycle of wear with different variants of the test.

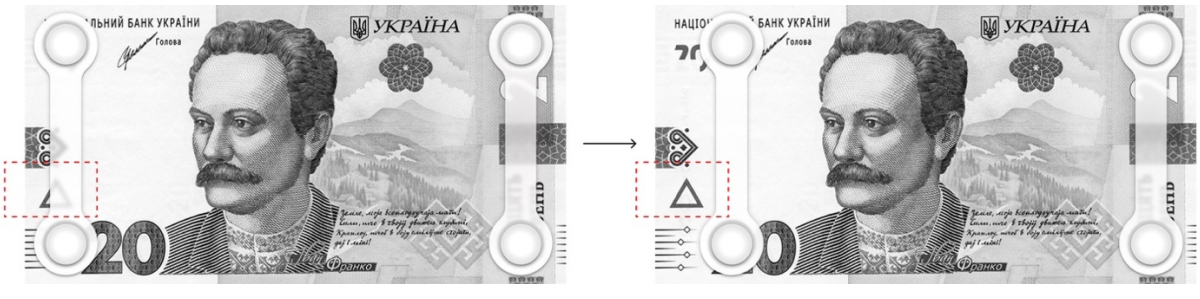

Fig. 1. Location of tapes with loaders

4. 2. 4. Procedure for determining changes in the microstructure and relief of the surface of the mark for people with visual impairments

A fragment of the triangular shape of the UAH 20 banknote MPVI was studied using a Nikon Eclipse 80i microscope (Japan) with a digital camera and a three-dimensional modeling function. An automated collection of images of this fragment from a microscope was carried out and a surface relief model was obtained with the possibility of *Z*-axis measurement. The resulting three-dimensional images are the simulated surface of the mark for people with visual impairments, which are exported in VRL format.

4. 3. Procedure for studying the influence of the level of wear on the identification of banknote denominations by people with visual impairments

In order to verify the preservation of the tactile characteristics of MPVI at wear, the evaluation of MPVI of 20-hryvnia banknotes of various degrees of wear by people with absolute vision loss was carried out with the assistance of the Central Board of the Ukrainian Society of the Blind in Kyiv. For testing, 20 new banknotes that were not subjected to artificial wear, 20 banknotes that passed one, two, and three wear cycles of various test options were provided. Two main criteria were determined, according to which the assessment of MPVI was carried out by people with visual impairments. This is the level of tactile sensation of the mark on banknotes with different degrees of wear and the accuracy of recognizing the geometric shape of the mark changed due to wear on banknotes with different degrees of wear.

The indicator of tactile identification of the denomination k was calculated as (1):

$$k = \frac{n_{id}}{N}, \quad (1)$$

where $i = \overline{1,3}$ is the number of passed artificial wear cycles, n_{id} is the number of identified banknote denominations, N is the total number of banknote samples from the selected group (N=20).

5. Results of research into the influence of the level of wear of banknotes on the change in the characteristics of banknotes

5. 1. Algorithm of the methodology for determining the impact of the level of wear of banknotes on the accessibility of banknotes for people with visual impairments

To achieve variability in the level of wear of banknote samples, 3 options for treating banknote samples in the circulation simulator were proposed. For each variant of the study, banknote samples were rotated at a speed of 60 min^{-1} for three 30-minute cycles in the wear simulator.

According to the first option, a contaminating mixture with a total weight of 1.5 g is added to the container of the simulator. According to the second option, a new portion of the contaminating mixture is not added to the container, and the banknotes are rotated with the remaining mixture after the tests according to the first option. To carry out the tests according to the third option, a new portion of the pollutant mixture with a total weight of 1.5 g is added to the container of the wear simulator. At the same time, the container with the wear components is not cleaned of the remains of the pollutant mixture after the first and second test options.

At the beginning of the first wear cycle, for each of the research options, twenty new test banknote samples are individually weighed, numbered, and placed in the banknote wear simulator.

At the end of the first and second wear cycles, the samples are taken out of the container, visually evaluated; the five banknotes that are visually the most worn are removed. To replace the withdrawn banknotes, five new ones are added to the test container and subjected to the next wear cycle in the banknote circulation simulator.

After the end of the last banknote degradation cycle, all banknotes are removed from the container. All withdrawn banknotes are weighed on analytical scales.

The devised algorithm of the methodology for determining the influence of the level of wear of banknotes on the accessibility of banknotes for people with visual impairments is shown in Fig. 2.

After carrying out each full cycle of banknote tests in the wear simulator according to three test options, the following samples were obtained:

– 30 banknotes after one cycle of degradation. Of these, fifteen banknotes were loaded into the circulation simulator before the first cycle and removed after the first wear cycle for each of the research options. The other fifteen banknotes were loaded into the circulation simulator before the third cycle and removed after the third wear cycle in each of the study options;

– 30 banknotes after two cycles of degradation. Of these, fifteen banknotes were loaded into the circulation simulator before the first cycle and removed after the second wear cycle for each of the research options. The other fifteen banknotes were loaded into the circulation simulator before the second cycle and removed after the third wear cycle in each of the study options;

– 30 banknotes after three cycles of degradation (all were placed in the container at the beginning of the first cycle of wear in each of the options).

5. 2. Results of studying the influence of the level of wear of banknotes on the characteristics of banknotes

5. 2. 1. Results of investigating the influence of the level of wear of banknotes on the change in the mass of banknotes

The results of studies of changes in the mass of ninety banknote samples during artificial wear under different test options are given in Table 2.

Fig. 3, 4 show the dependence of changes in the weight of banknotes on the level of wear of banknotes.

Fig. 5 shows a dependence of the average value of the increase in the mass of banknotes depending on the number of completed cycles, the test option, and the option of introducing and removing samples from the circulation simulator.

According to the results of the study of changes in the mass of banknotes, it was determined that the number of cycles of artificial wear directly affects the accumulation of dirt on banknote samples (Fig. 3, 4). This is manifested both in the increase in the average value of the increase in the mass of banknotes, and in the increase in the mass of accumulated dirt on banknote samples.

It was determined that after the end of the tests, according to the first option, the banknotes absorbed 82.8 % (1242.1 mg), according to the second option – 72.2 % (186.4 mg), according to the third option – 84.9 % (1333.2 mg) of the polluting mixture. The weight of the pollutant mixture at the beginning of each variant of the study was 1500 mg, 258.4 mg, 1572.2 mg, respectively.

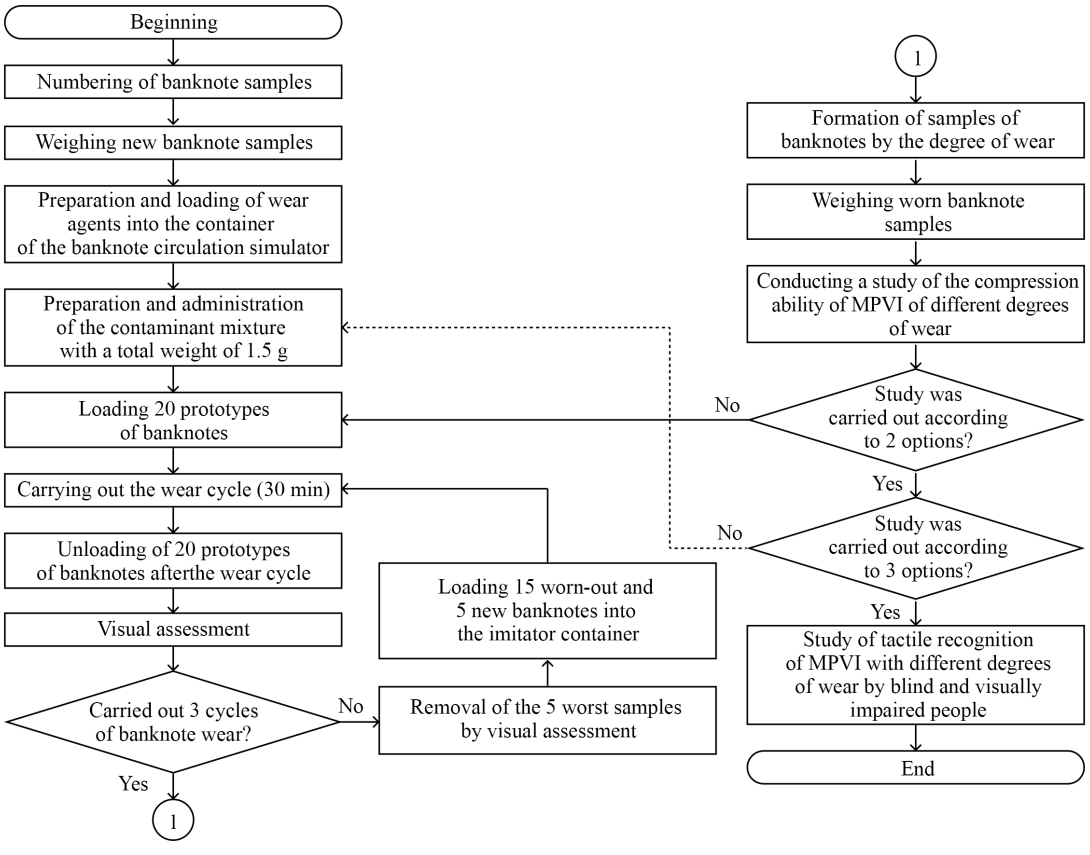

Fig. 2. Algorithm of the methodology for determining the influence of the level of wear of banknotes on the accessibility of banknotes for people with visual impairments

Table 2

Results of research into changes in the mass of banknote samples during artificial wear under different test options

Wear cycle	Indicator	Designation of the indicator, set of the samples of banknotes	Value
1	2	3	4
Test option 1 (the total amount of the contaminant mixture at the beginning of the test was 1.5 g)			
1	Average increase in banknote weight, g	$\bar{m}^1_{5i}, i\in\{1,20\}$	0.054
		$\bar{m}^1_{5i}, i=[26,30]$	0.013
	Weight of accumulated dirt on banknote samples per cycle, g	$M^1_{10i}, i\in\{1,20\}\cup i=[26,30]$	0.338
2	Average increase in banknote weight, g	$\bar{m}^2_{5i}, i\in\{1,20\}$	0.055
		$\bar{m}^2_{5i}, i=[21,25]$	0.013
	Weight of accumulated dirt on banknote samples per cycle, g	$M^2_{10i}, i\in\{1,20\}\cup i=[21,25]$	0.387
3	Average increase in banknote weight, g	$\bar{m}^3_{10i}, i\in\{1,20\}$	0.051
	Weight of accumulated dirt on banknote samples per cycle, g	$M^3_{10i}, i\in\{1,20\}$	0.516
1–3	The total weight of accumulated dirt on banknote samples for the full test cycle, g	$M^3_{30i}, i=[1,30]$	1.242
Test option 2 (the total amount of the contaminant mixture at the beginning of the test was 0.258 g)			
1	Average increase in banknote weight, g	$\bar{m}^1_{5i}, i\in\{31,50\}$	0.009
		$\bar{m}^1_{5i}, i=[56,60]$	0.001
	Weight of accumulated dirt on banknote samples per cycle, g	$M^1_{10i}, i\in\{31,50\}\cup i=[56,60]$	0.055
2	Average increase in banknote weight, g	$\bar{m}^2_{5i}, i\in\{31,50\}$	0.008
		$\bar{m}^2_{5i}, i=[51,55]$	0.004
	Weight of accumulated dirt on banknote samples per cycle, g	$M^2_{10i}, i\in\{31,50\}\cup i=[51,55]$	0.061

Continuation of Table 2

1	2	3	4
3	Average increase in banknote weight, g	$\bar{m}^3_{10i}, i \in \{31,50\}$	0.007
	Weight of accumulated dirt on banknote samples per cycle, g	$M^3_{10i}, i \in \{31,50\}$	0.069
1–3	The total weight of accumulated dirt on banknote samples for the full test cycle, g	$M^3_{30i}, i=[31,60]$	0.186
Test option 3 (the total amount of the contaminant mixture at the beginning of the test was 1.572 g)			
1	Average increase in banknote weight, g	$\bar{m}^1_{5i}, i \in \{61,80\}$	0.059
		$\bar{m}^1_{5i}, i=[86,90]$	0.013
	Weight of accumulated dirt on banknote samples per cycle, g	$M^1_{10i}, i \in \{61,80\} \cup i=[86,90]$	0.365
2	Average increase in banknote weight, g	$\bar{m}^2_{5i}, i \in \{61,80\}$	0.059
		$\bar{m}^2_{5i}, i=[81,85]$	0.022
	Weight of accumulated dirt on banknote samples per cycle, g	$M^2_{10i}, i \in \{61,80\} \cup i=[81,85]$	0.407
3	Average increase in banknote weight, g	$\bar{m}^3_{10i}, i \in \{61,80\}$	0.056
	Weight of accumulated dirt on banknote samples per cycle, g	$M^3_{10i}, i \in \{61,80\}$	0.560
1–3	The total weight of accumulated dirt on banknote samples for the full test cycle, g	$M^3_{30i}, i=[61,90]$	1.332

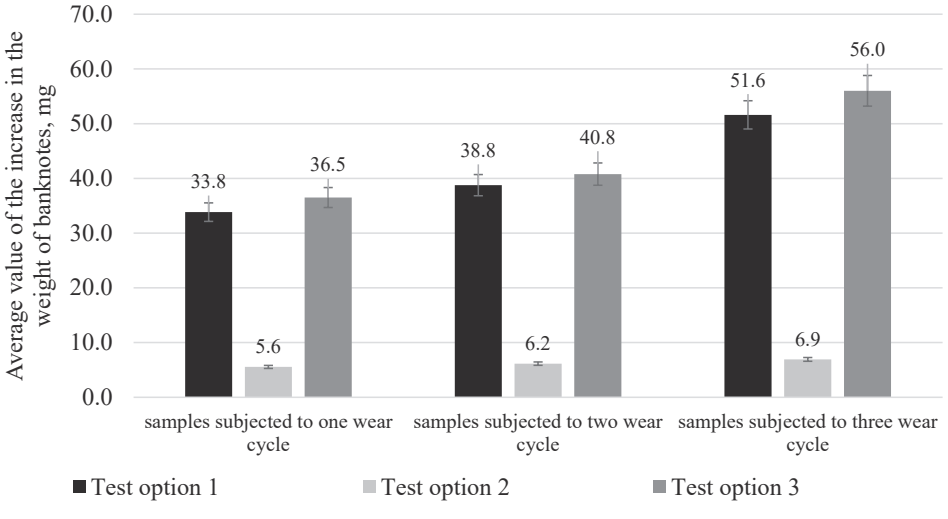

Fig. 3. Average value of the increase in the weight of banknotes depending on the number of cycles passed and the test option, mg

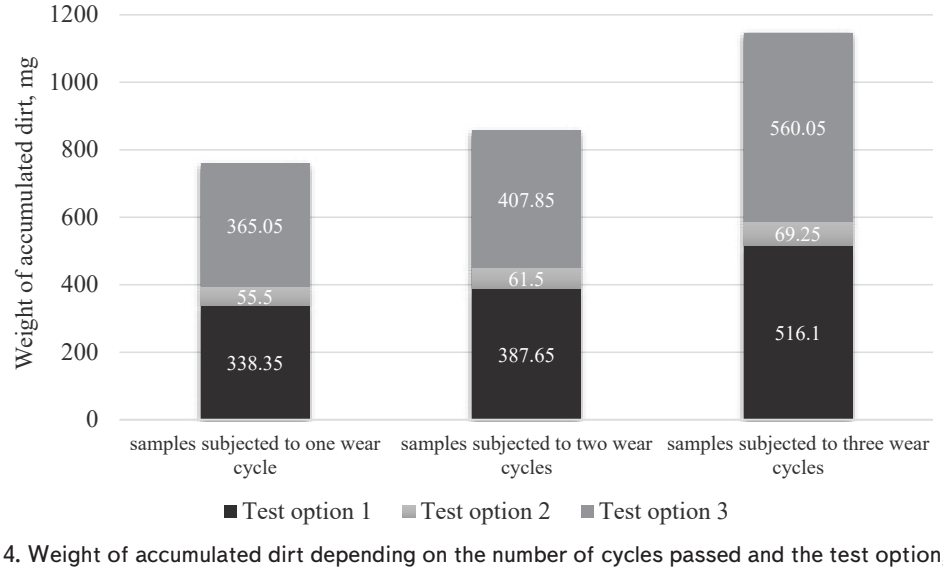

Fig. 4. Weight of accumulated dirt depending on the number of cycles passed and the test option, mg

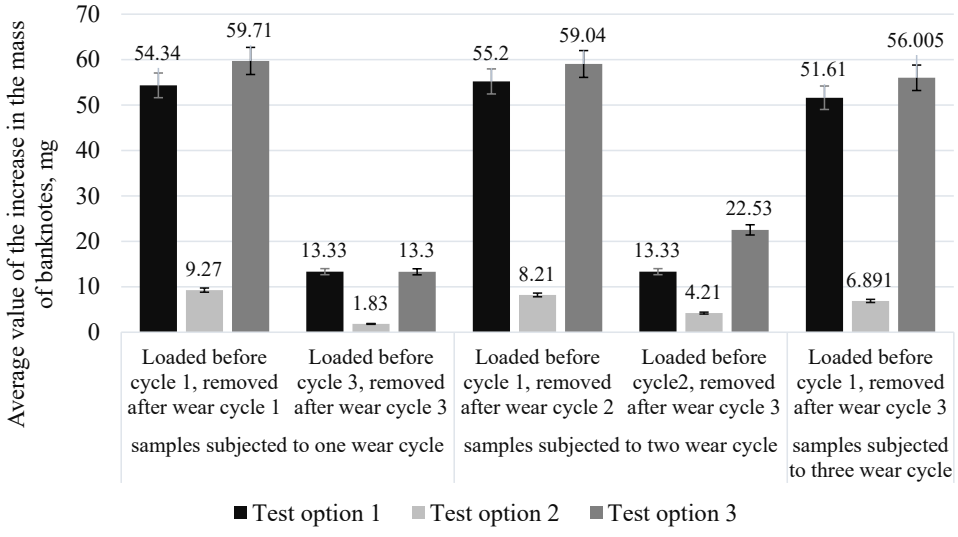

Fig. 5. Average value of the increase in the mass of banknotes depending on the number of completed cycles, the variant of tests, and the variant of introducing and removing samples from the circulation simulator, mg

It was determined that banknote samples subjected to the first wear cycle accumulate significantly more dirt than banknote samples subjected to the third wear cycle in the circulation simulator. Similar dynamics of dirt accumulation were also observed for banknote samples subjected to two wear cycles in the banknote circulation simulator. The average values of mass increase of banknotes that were loaded into the banknote circulation simulator before the first cycle and removed after 1, 2, and 3 wear cycles differ slightly for all test variants.

5. 2. 2. Results of investigating changes in the ability of the mark for people with visual impairments to compress when banknotes are worn

It was established experimentally that the change in the height of MPVI as a result of the compression test occurs during the first minute. The values in Fig. 6 show that wear during two cycles causes an increase in the average value of compression of MPVI, and, therefore, reduces the tactile perception. This phenomenon negatively affects the recognizability of the denomination of the banknote by people with visual impairments.

A decrease in the average values of compression of MPVI after three cycles of wear of banknotes in the circulation simulator may indicate a significant erosion of the height of the ink layer at this stage.

5. 2. 3. Results of investigating changes in the microstructure and surface relief of the mark for people with visual impairments when banknotes are worn

A change in the height of an MPVI ink layer was investigated in the specified area (Fig. 7) using a microscope with a digital camera and a three-dimensional modeling function according to the above-described procedure (Fig. 8–11).

During the photography and formation of a three-dimensional image of MPVI with different degrees of wear, the destruction of the layer of intaglio ink after each wear cycle was determined (Fig. 12).

Fig. 12 demonstrates that the average height of the ink layer of the intaglio print after the first cycle of wear decreases by more than half, and during the following cycles of wear, it decreases much more slowly.

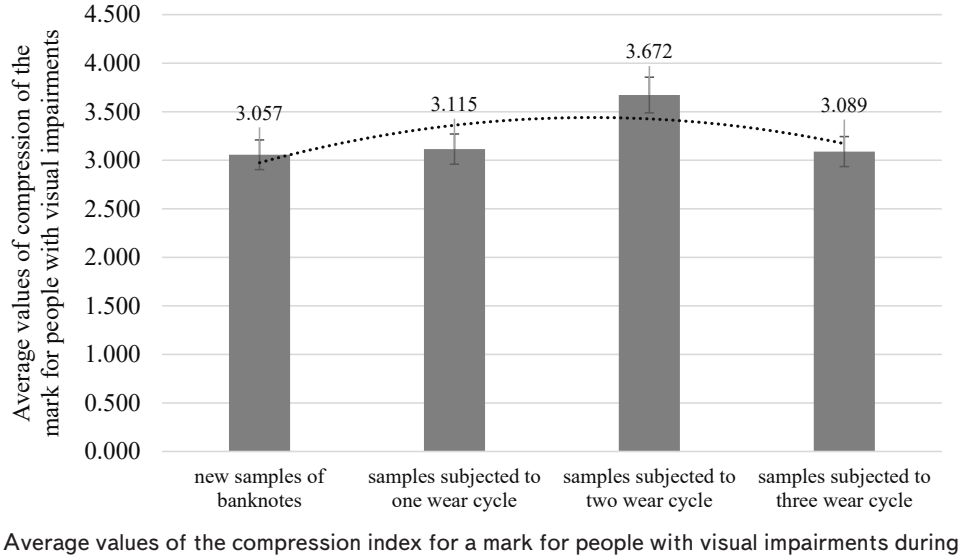

Fig. 6. Average values of the compression index for a mark for people with visual impairments during 1 min depending on the number of passed wear cycles

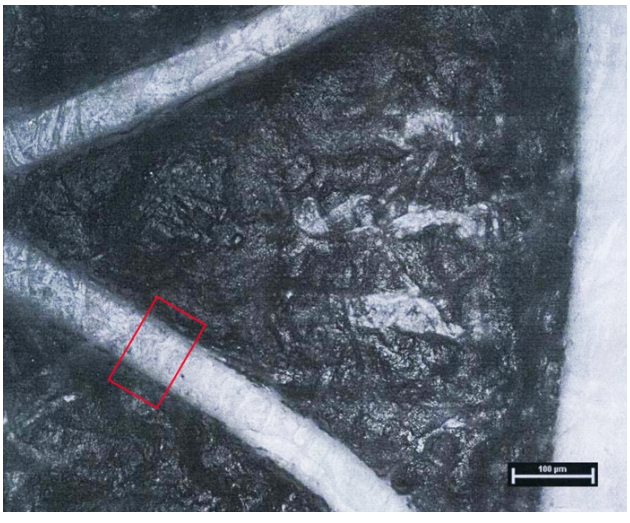

Fig. 7. Section of the mark for the visually impaired on the UAH 20 banknote, which was studied

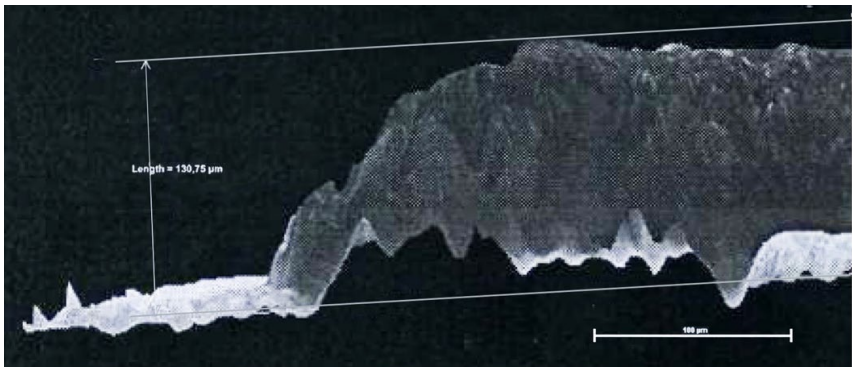

Fig. 8. An enlarged part of the mark for the visually impaired on the new banknote

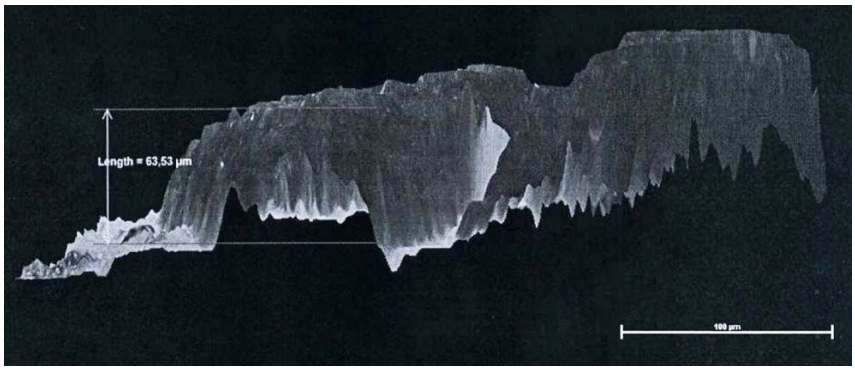

Fig. 9. Enlarged part of the mark for visually impaired people after the first cycle of artificial wear

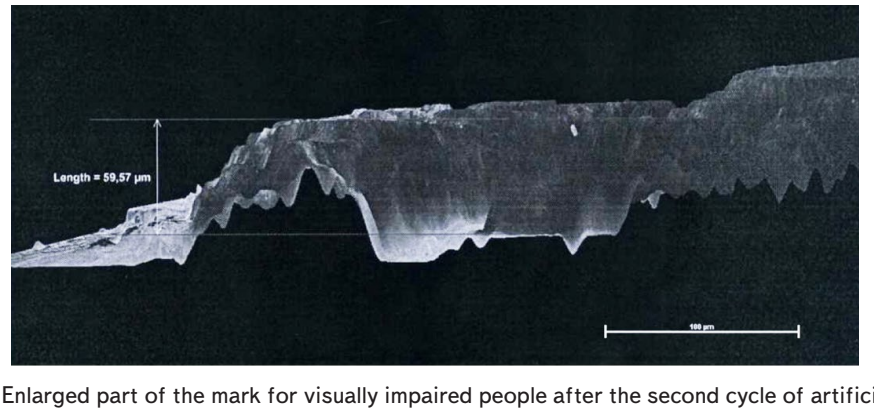

Fig. 10. Enlarged part of the mark for visually impaired people after the second cycle of artificial wear

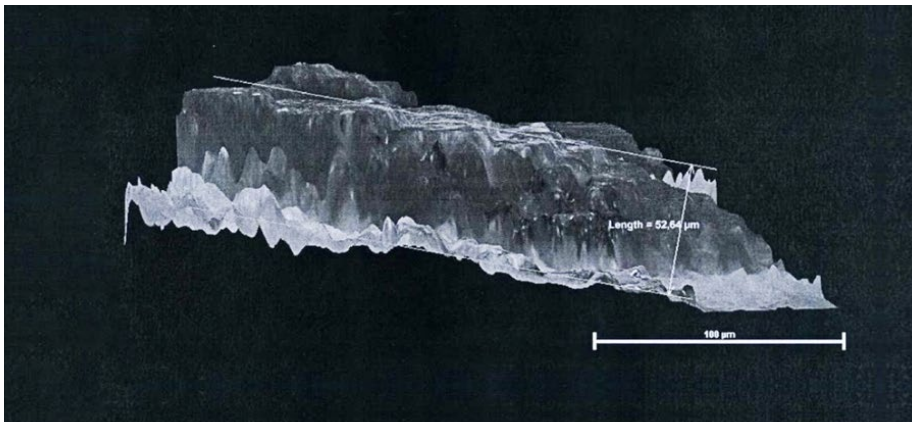

Fig. 11. Enlarged part of the mark for people with visual impairments after the third cycle of artificial wear

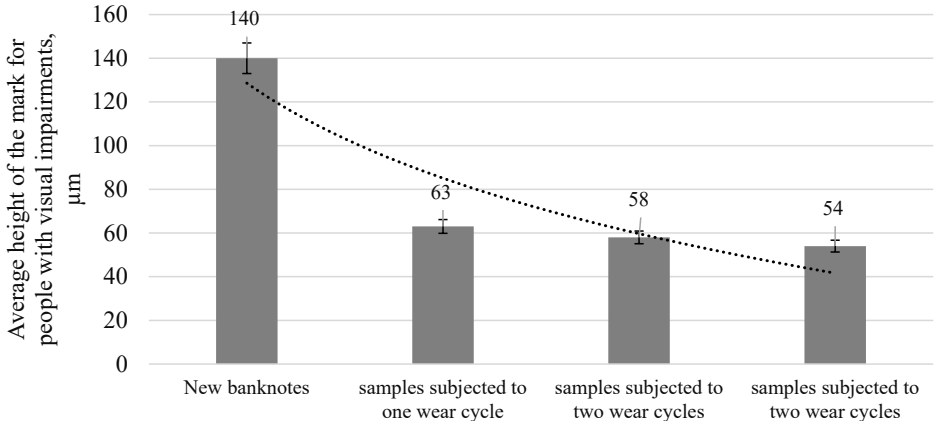

Fig. 12. Average values of the height of a mark for people with visual impairments depending on the number of cycles completed

5. 3. Results of studying the influence of the level of wear on the identification of banknote denominations by visually impaired people

Fig. 13 clearly shows the dependence of the average values of the index of tactile identification of the denomination of banknotes by people with absolute vision loss on the level of wear of banknotes.

Fig. 13 clearly shows that the denomination identification on new banknotes and banknotes after one wear cycle was successful. The denominations of the banknote after the second wear cycle were mostly identified, but there were cases of unsatisfactory identification. The results of tactile recognition of banknote denominations after the third wear cycle are unsatisfactory.

Fig. 14 shows the dependence of banknote characteristics on the level of their wear.

There is a clear positive dependence of the mass of accumulated dirt on the level of wear of banknotes, and a negative dependence of the height of MPVI and the level of tactile identification on the level of wear of banknotes. The compression values of MPVI increase until the 2nd wear cycle, after which they return to the initial values.

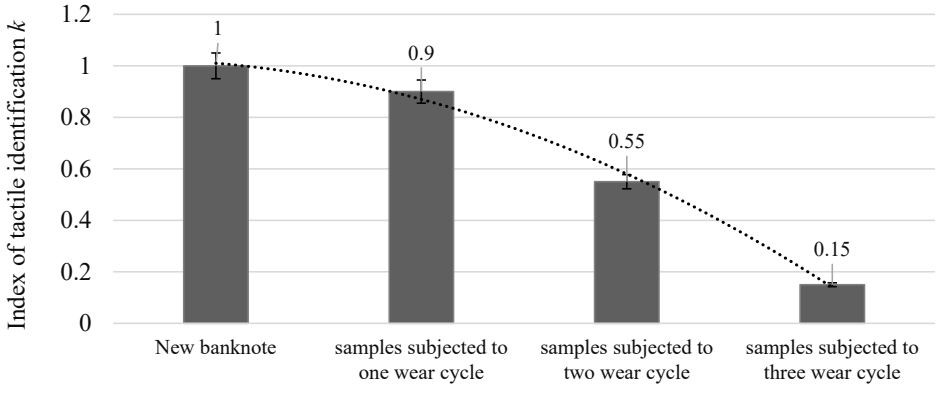

Fig. 13. Average values of the index of tactile identification of banknote denominations by people with total vision loss depending on the number of completed cycles

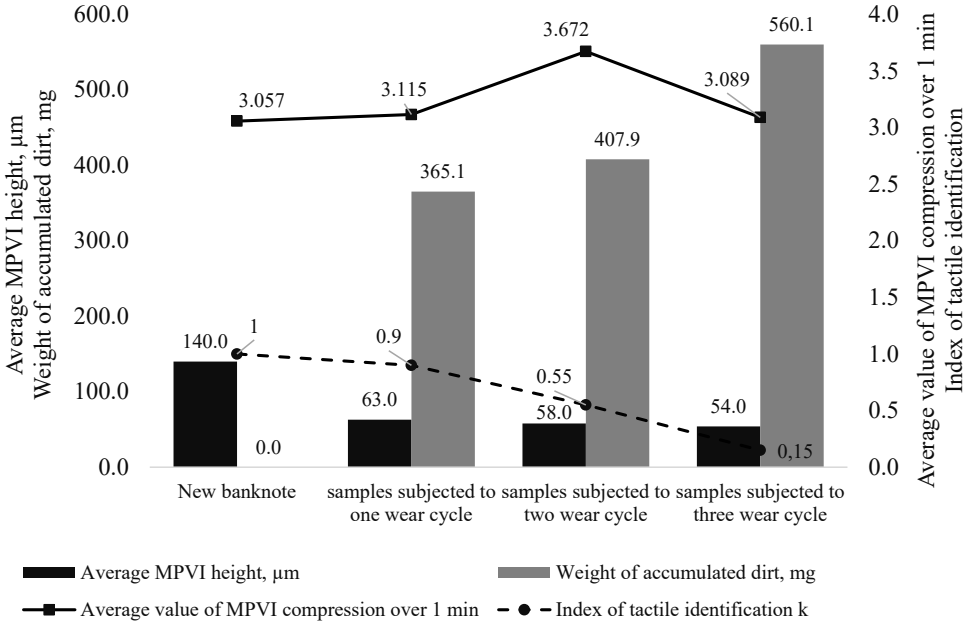

Fig. 14. Dependence of banknote characteristics on the level of wear

6. Discussion of results of investigating the impact of the level of wear of banknotes on changes in the characteristics of banknotes

One of the main results of our research is the developed algorithm of the methodology for determining the influence of the level of wear of banknotes on the accessibility of banknotes for people with visual impairments (Fig. 2). The basis for the development was a method from [7]; however, according to the developed algorithm, the variability of introducing and withdrawing banknote samples into the circulation simulator was implemented. This has made it possible to analyze the process of the mechanism of dirt accumulation by banknotes and general wear.

In [7], it was noted that despite the significant destruction of the structure, the tearing of banknotes occurred exclusively along the protective tape, which indicated that the banknote did not lose its rigidity. Therefore, the algorithm provided for the use of a pollutant mixture, the composition of which is given in Table 1. The components of the mixture in the process of treating banknotes in the circulation simulator gave the banknotes elasticity. This has made it possible to approximate the nature of the contamination to that which corresponds to the actual circulation of the banknote.

The algorithm implies conducting research into the impact of the level of wear of banknotes on the characteristics of banknotes. In contrast to the methodology in [9], the algorithm involves a study of changes in the capability of the mark for people with visual impairments to compress when banknotes are worn and a study of changes in the microstructure and relief of the surface of the mark for people with visual impairments when banknotes are worn. This makes it possible to more fully analyze the process of wear of marks for people with visual impairments and to derive correlational dependences between the characteristics of banknotes at different stages of wear.

The main distinguishing feature of the algorithm was to conduct a study into the effect of the level of wear on the identification of banknote denominations by visually impaired people. In contrast to the method described in [10], banknotes of different degrees of wear were studied. Also, according to the methodology, people with absolute vision loss were involved in the testing. This increases the adequacy of the evaluation of respective marks for their suitability for further circulation.

To verify the devised methodology according to the developed algorithm, experimental studies were conducted. It was experimentally confirmed (Fig. 3–5) that the banknotes absorb the main part of the polluting mixture during one wear cycle (over the first 30 minutes of processing in the wear simulator). During subsequent cycles of wear, banknotes become less intensively contaminated. This can be explained by the developed microstructure of the surface of the new banknotes. First, during one wear cycle, the contaminant mixture accumulates in the pores of the paper base of the banknotes. The limited volume of pores does not allow further accumulation of dirt in the structure of the banknote. Second, the thick ink layers of intaglio printing applied to the surface of the banknotes provide high indicators of the roughness of the surface of the banknotes. Accordingly, they accumulate a significant part of the polluting mixture during the first wear cycle. However, further erasure of the ink layer of the intaglio printing, accordingly, reduces the roughness of the banknote surface, and, therefore, the total mass of accumulated dirt.

The results of MPVI compression tests, conducted according to the devised methodology, confirm the abrasion of the ink layer during wear. This, in turn, leads to a loss of rigidity and, accordingly, to an increase in elasticity. In particular, it was determined (Fig. 6) that after the 2nd cycle of wear there is a significant increase in the elasticity of MPVI, which is explained by the critical contamination of the base of the banknote with a contaminating mixture.

Microscopic studies also confirmed the erasure of the ink layer of intaglio printing during wear (Fig. 8–11), noted in previous studies of the quality of intaglio printing [12–14].

However, the improved procedure has made it possible to determine that the main destruction of the mark for people with visual impairments also occurs in the first cycle of wear (Fig. 12), the level of destruction decreases in the second and third cycles.

Abrasion of the ink layer and increase in elasticity, as a result, reduce the level of tactile perception of MPVI and negatively affects the identification of the denomination of the banknote, which is confirmed by the tests of MPVI after each cycle of wear. The results of investigating tactile recognition of MPVI (Fig. 13) demonstrated that banknotes after the second cycle of artificial wear cannot be identified by people with visual impairments.

It is worth noting that during these studies, the following peculiarities of recognition of the denominations of Ukrainian hryvnia banknotes by people with total vision loss and the sequence of their actions regarding the determination of the denomination were revealed:

1) to recognize the denomination of a banknote, a person with absolute vision loss first of all searches for the image of the denomination printed with intaglio printing on the banknote, which is located in the lower left corner of the front side of the banknote;

2) then s/he probes the relief of the band of continuous printing with intaglio printing (portrait and vertical ornament);

3) only at the third stage, s/he does the MPVI check, explaining this by the fact that this mark is tactilely felt mainly while the banknote has minimal wear, and then with an increase in the degree of wear, the relief of the mark is practically not felt.

Such features of the perception of Ukrainian hryvnia banknotes indicate that in order to improve the recognizability of the denominations, it is worth continuing the research into the placement, type, and size of MPVI, involving a wider audience of people with vision problems. In order to increase the inclusiveness of Ukrainian society, this will be a component of further research.

Having analyzed Fig. 14, it was determined that from the point of view of the accessibility of banknotes to the visually impaired, the properties of banknotes after the second cycle of wear are determined to be critical for the withdrawal of such banknotes from circulation. MPVI compression indicators, which reach their maximum value precisely on samples subjected to two wear cycles, can be taken as a basis for rejecting banknotes from circulation. Determining the value of this indicator for each banknote denomination is one of the areas of further research.

Thus, the regularities revealed during the experimental studies confirm the feasibility of improving the procedure for determining the level of wear of the mark for people with visual impairments on Ukrainian hryvnia banknotes. This method does not require expensive and heavy equipment, as in the procedures of banknote denomination identification based on image processing [4–6]. The method can be used by banknote manufacturers at the stage of their development. The obtained features can be taken into account both during the adjustment of sorting equipment to determine the suitability of banknotes for further circulation, and during the improvement of the technological process of intaglio printing.

The main drawback of the procedure is low automation of the research process, which leads to an increase in the duration of research. Increasing the automation of conducting research will be an additional direction for further improvement of the methodology for determining the level of wear of marks for people with visual impairments.

The proposed improvement of the procedure for determining the level of wear of a mark for people with visual impairments on banknotes can be applied exclusively to marks printed with intaglio printing on paper bases. This is due to the mechanism of destruction of the color layers of intaglio printing during the circulation of banknotes.

7. Conclusions

1. An algorithm for the procedure of determining the level of mark wear is proposed, which provides for the variability of introducing and withdrawing banknote samples into the circulation simulator. This has made it possible to analyze the process of the mechanism of dirt accumulation by banknotes and general wear. The composition of the contaminating mixture has been improved, which ensured that the nature of the contamination is closer to that which corresponds to the actual circulation of the banknote.

2. Experimental studies were performed into the influence of the level of wear of banknotes on changes in the mass of banknotes, changes in the compressibility of MPVI (the level of elasticity), changes in the microstructure and surface relief of MPVI. Step-by-step weighing of the samples and microscopic studies experimentally confirmed the erosion of the ink layer of the intaglio print and the accumulation of dirt throughout the wear. However, it was noted that the greatest contamination of banknotes and the main destruction of MPVI occur during one wear cycle (over the first 30 min of processing in the wear simulator). During subsequent wear cycles, banknotes become less intensively contaminated, and the level of destruction of MPVI decreases. The results of the compression tests of MPVI, carried out according to the devised methodology, have made it possible to determine that after the 2nd cycle of wear there is a significant increase in the elasticity of MPVI, which is explained by the critical contamination of the base of the banknote with a contaminating mixture.

3. The testing of MPVI of different levels of wear by people with absolute loss of sight for the identification of banknote denominations was carried out. The results of investigating tactile recognition of MPVI demonstrated that banknotes after the second cycle of artificial wear cannot be identified by visually impaired people. Thus, it is determined that from the point of view of accessibility of banknotes for all population groups, including the visually impaired, the properties of banknotes after the second cycle of wear have been determined to be critical for removing such banknotes from circulation. MPVI compression indicators, which reach their maximum value precisely on samples subjected to two wear cycles, can be taken as a basis for rejecting banknotes from circulation.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

The data will be provided upon reasonable request.

Acknowledgments

The authors of the work express their gratitude to the Banknote and Mint of the National Bank of Ukraine for the production of experimental samples and assistance in organizing the research, as well as to the Central Board of the Ukrainian Society of the Blind in Kyiv for assistance in testing experimental samples of banknotes among people with impaired vision.

References

1. World report on vision (2019). Geneva: World Health Organization, 180. Available at: https://www.who.int/publications/i/item/9789241516570
2. Springer, K., Subramanian, P., Turton, T. (2015). Australian Banknotes: Assisting People with Vision Impairment. Reserve Bank of Australia. Available at: https://www.rba.gov.au/publications/bulletin/2015/mar/1.html
3. Kyrychok, A. (2018). The overview of investigation in the field of banknote design for visually impaired people. EUREKA: Physics and Engineering, 3, 33–41. doi: https://doi.org/10.21303/2461-4262.2018.00639
4. Shaker, S., Gheni Alawan, M. (2018). Paper Currency Detection based Image Processing Techniques: A review paper. Journal of Al-Qadisiyah for Computer Science and Mathematics, 10 (1). doi: https://doi.org/10.29304/jqcm.2018.10.1.359
5. Gupta, I., Kamble, S., Nisar, K., Patel, P., Gogate, V. (2022). Currency Detector System for Visually Impaired. International Journal for Research in Applied Science and Engineering Technology, 10 (5), 1184–1186. doi: https://doi.org/10.22214/ijraset.2022.42256
6. Madhura, Viditha, Manjesh, R. (2020). Currency Recognition for Blind. International Journal for Research in Applied Science and Engineering Technology, 8 (5), 597–600. doi: https://doi.org/10.22214/ijraset.2020.5094
7. Lee, J., Hong, H., Kim, K., Park, K. (2017). A Survey on Banknote Recognition Methods by Various Sensors. Sensors, 17 (2), 313. doi: https://doi.org/10.3390/s17020313
8. Bartz, W. J., Crane, T. T. (2006). Circulation simulator method for evaluating bank note and optical feature durability. SPIE Proceedings. doi: https://doi.org/10.1117/12.650725
9. Kyrychok, T., Baglai, V., Kyrychok, A. (2020). Optical methods of banknotes sorting for Ukrainian Hryvnia: results and problems. Fourteenth International Conference on Correlation Optics. doi: https://doi.org/10.1117/12.2553936
10. Kyrychok, T., Shevchuk, A., Nesterenko, V., Kyrychok, P. (2013). Banknote Paper Deterioration Factors: Circulation Simulator Method. BioResources, 9 (1). doi: https://doi.org/10.15376/biores.9.1.710-724
11. Summers, I. R., Irwin, R. J. (2005). Tactile discrimination of paper. Biomedical Physics Group. Proceedings Haptex '05 – Workshop on Haptic and Tactile Perception of Deformable Objects. Hannover. Available at: https://www.academia.edu/11487151/Tactile_discrimination_of_paper
12. Kyrychok, T., Kyrychok, P., Havenko, S., Kibirkštis, E., Miliūnas, V. (2014). The influence of pressure during intaglio printing on banknotes durability. Mechanics, 20 (3). doi: https://doi.org/10.5755/j01.mech.20.3.7393
13. Jin, O., Qu, L., He, J., Li, X. (2015). Recognition of New and Old Banknotes Based on SMOTE and SVM. 2015 IEEE 12th Intl Conf on Ubiquitous Intelligence and Computing and 2015 IEEE 12th Intl Conf on Autonomic and Trusted Computing and 2015 IEEE 15th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UIC-ATC-ScalCom). doi: https://doi.org/10.1109/uic-atc-scalcom-cbdcom-iop.2015.53
14. Baek, S., Lee, S., Choi, E., Baek, Y., Lee, C. (2019). Banknote simulator for aging and soiling banknotes using Gaussian models and Perlin noise. Expert Systems with Applications, 137, 405–419. doi: https://doi.org/10.1016/j.eswa.2019.07.013