Designing a Fuzzy Controller for Prediction of Tactile Product Quality

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Abstract. Designing a tactile product for the visually impaired people is a complex multifactorial process. An instrument for ensuring the effective implementation of this process is the ability to determine the predicted quality of tactile product perception. The research and modelling of the process components, a formalised description of the factors that characterise the assessment process of the tactile product quality and determining the extent of their impact on the tactile surface perception provide a reasonable choice of parameters for the creation of a tactile product. The suggested study has developed a simulation model for the quality assurance of tactile products, depending on the quality level of linguistic terms, which has made it possible to construct an expert-modelling system "Fuzzy controller of the tactile product quality".

Keywords: tactile product, quality, simulation model, fuzzy logic, linguistic term, membership function.

1 Introduction

Human activity occurs in a complex, dynamic environment and requires the ability to navigate the environment, adapt the actions to it. A person acquires the knowledge about the external and internal world in the course of sensual and logical perception of the reality through cognitive psychic processes: feeling, perception, thinking, imagination. Cognitive activity always begins with a sensual reflection of the world in feelings and perception. The feelings of a person reveal the colours and sounds, smells and tastes, weight, warmth or coldness of the things that surround him. In addition, the feelings give the information about changes in one's body: a person feels a disturbance in the functioning of the internal organs, the position and movement of his body and its individual parts. Feelings as images reflecting the individual properties of objects and arising in the activity of any organs of the senses in a more complex and developed form than the senses, but closely related to sensory cognition of the world are perceptions.

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An important global problem is the adaptation of the visually impaired people to the environment, as the number of blind people unfortunately increases annually. Therefore, it is relevant to study the aspects of the information tactile perception by the blind and search for new improved methods of identification of objects, phenomena, everyday goods by such people. A special group consists of blind or visually impaired children of preschool and school age who are just beginning to learn about the world, studying the objects by their description and tactile perception, not having the slightest idea of their shapes, smells, other important characteristics, unable to read Braille yet. The solution to this problem is possible through the creation of appropriate information tools for the formation and predictive assessment of the tactile product quality on the basis of fuzzy sets theory and methods of system analysis, which will help in manufacturing the proper products.

2 Formal problem statement

The task of the quality assessment of the perception of the tactile product (TP), the determination of its characteristics is a complex technological procedure and it is solved on the basis of the assessment of influence factors [1, 2], such as finding a reflexion $X = (x_1, x_{2,} ... x_n) \to y_j \in Y = (y_1, y_2, ... y_m)$, where X is a set of factors influencing the tactile information perception, Y is a set of options-predictions for designing. To solve this problem, we use the tools of logic programming, in which the basis of high-level language is the logic of first-order predicates in the form of Horn clauses. According to this method, a prediction can be obtained from the vector of factors (x_1, x_2,.., x_n) if there is a chain of reasoning in the expert knowledge base: IF $x_1 \bigcap x_2 \bigcap ... \bigcap x_n$ THEN y_i.

Intelligent technology, designed on the complex use of fuzzy logic, is used to formalize the connection of inputs and outputs of the technological process of modelling objects. The advantage of fuzzy logic is the ability to use the expert knowledge in the form of linguistic variables (LV) associated with the rules "IF <inputs>, THEN <output>". The interrelationships of the individual factors are formalized by linguistic variables and analysed at three hierarchical levels, namely: system level $Q = F_Q(H,\ P,\ Z)$; the component of a tactile surface $H = F_H(h_1, h_2, h_3)$; the formation of a tactile surface $P = F_P(p_1, p_2, p_3)$; the perception of the tactile product content $Z = F_Z(z_1, z_2, z_3, z_4)$. The hierarchical set of relations corresponds to the developed tree of fuzzy logical inference.

We use fuzzy logical equations for modelling that relate the membership functions to different levels of input and output linguistic variables. Each fuzzy logical equation is matched by a knowledge base that is determined by expert judgement regarding the relationships of fuzzy input and output linguistic terms. The quality of the tactile process perception includes the following:

– $T(Q) = \langle low,\ medium,\ high \rangle$ – the quality of the perception of the product content;

– $T(H) = \langle low,\ medium,\ high \rangle$ – the quality of the components of the tactile surface;

– $T(P) = \langle low,\ medium,\ high \rangle$ – the quality of the formation of the tactile surface;

– $T(Z) = \langle low,\ medium,\ high \rangle$ – the quality of the perception of the product content.

As a result of the calculations performed on the linguistic variables *H, P, Z*, it is possible to determine the term-sets of the linguistic variable *Q* "the quality of the perception of the tactile information". We form the term-set *T (q)* = <low, medium, high> for the linguistic variable *Q*.

The quantitative values of the variable *Q* are presented by three dots on the universal set $U(q) = \{q_1, q_2, q_3\}$.

As a result, the linguistic variable *Q* "the quality of the perception of the tactile information" will be presented as a fuzzy set:

$$Q(H,P,Z) = \left\{ \frac{\mu_{low}(Q)}{q_1}; \frac{\mu_{medium}(Q)}{q_2}; \frac{\mu_{high}(Q)}{q_3} \right\} \quad (1)$$

According to the model of fuzzy logical inference, the procedure for determining the quality of the tactile product perception is two-level and allows one to obtain a numerical value of the result from arbitrary combinations of the output parameters values based on the rules "IF – THEN" of the expert knowledge base [5].

3 Literature review

The problem of the information reproduction for the blind is extremely relevant and backed up by the rapid development of the latest technologies used by the publishing and printing industry. Relief images intended to be read by the blind people fingers can be reproduced using different technologies and methods [1-6].

An analytical review of scientific sources, patent and technical-regulatory documentation in this area indicates a clear dominance of the humanitarian trend of the conducted research, since most of the works are devoted to problems of social and psychological adaptation of visually impaired people and their information support [8-11].

A person receives a variety of information about the world; he perceives all its various aspects through the sensory system or sense organs. The role of feeling and perception in our lives is so significant that there is a need to maintain an information balance with the environment, the violation of which leads to the personality disorganization and disorders in the body functioning. An artificial information hunger can arise due to the limitations of visual, audio, tactile, motor and other stimuli, which always serve as the usual background of human activity [12, 13].

The results of the books analysis available for the blind in Lviv region in the library fund and Braille marking of label-packaging products indicate the insufficiency of providing the blind with printed information. Therefore, the search for new techno-

logical solutions to reproduce the information in Braille is an extremely urgent task for experts in the printing industry.

Despite the obvious progress in the area of obtaining the information for the blind due to the development of computer technologies, which has enabled many people to discover enormous opportunities to obtain the necessary information, its processing, etc., there are many blind people (including young people) in Ukraine deprived of this possibility for various reasons, mainly financial ones. 4% of audio books have been created in the world for the blind people and it makes only a few hundreds of a per cent of the total number of Braille books. Therefore it is understandable that the tactile perception in typhlology begins to receive special attention, as the sense of the information it reproduces is more identical to the vision [14, 15].

Domestic and foreign typhlologists have already accumulated some experience in the production of tactile images with the use of various technologies, so that the blind have some opportunities that allow at least minimal compensation for the disadvantages of the visual system. So tactile products are powerful tools for the development and perception of a blind person [16-19].

The analysis of the literature sources indicates that there is no information approach to the problem of the quality assessment of the tactile product. The core of the study lies in the development of a simulation model which is the basis of a fuzzy controller predicting the quality of tactile products.

4 Objectives of the work (problem setting)

Designing a structural and functional model of the information technology for predicting the image perception quality. The development of the information technology, presented in five stages, each of which defines a separate action for the collection, analysis, modelling, synthesis of information to determine the quality of tactile product perception by visually impaired people and the implementation of the expert-modelling calculation system of the quality indicator of the tactile product perception at the final stage.

5 Materials and methods

The solution to the problem of finding the level of the quality assurance of the tactile product design will be determined by setting values of membership functions calculated on the basis of original values of linguistic variables formulated by experts [5]. They will be determined on the basis of a term-set of values of linguistic variables: the diameter of Braille dot in mm – LV h_1 "a dot diameter"; Braille dot height in mm – LV h_2 "a dot height"; the density of Braille characters in mm – LV h_3 "density of characters"; the method of Braille reproduction (c.u.) – LV p_1 "a reproduction method"; the material base for Braille application (c.u.) – LV p_2 "a material base"; the material for Braille dot formation (c.u.) – LV p_3 "dot material"; a type of tactile product (c.u.) – LV z_1 "a product type"; the age of the TP reader (c.u.) – LV z_2 "age of reader"; the experience of the TP reader (c.u.) – LV z_3 "reading experience"; the intel-

ligence level (c.u.) – LV z_4 "intelligence" [8-10, 13]. We get: $h_1 = 1{,}4$; $h_2 = 0{,}55$; $h_3 = 6{,}2$; $p_1 = 4$; $p_2 = 3$; $p_3 = 3$; $z_1 = 3$; $z_2 = 2$; $z_3 = 3$; $z_4 = 4$.

According to the given data, the following values of the membership functions of linguistic variables are defined:

$\mu_{small}(h_1) = 0{,}33$; $\mu_{medium}(h_1) = 0{,}81$; $\mu_{big}(h_1) = 0{,}75$;
$\mu_{small}(h_2) = 0{,}22$; $\mu_{medium}(h_2) = 0{,}34$; $\mu_{big}(h_2) = 0{,}78$;
$\mu_{small}(h_3) = 0{,}25$; $\mu_{medium}(h_3) = 0{,}5$; $\mu_{big}(h_3) = 0{,}67$;
$\mu_{acceptable}(p_1) = 0{,}42$; $\mu_{standard}(p_1) = 0{,}63$; $\mu_{satisfactory}(p_1) = 0{,}77$;
$\mu_{conventional}(p_2) = 0{,}55$; $\mu_{sufficient}(p_2) = 1$; $\mu_{improved}(p_2) = 0{,}45$;
$\mu_{conventional}(p_3) = 0{,}55$; $\mu_{sufficient}(p_3) = 1$; $\mu_{improved}(p_3) = 0{,}66$;
$\mu_{universal}(z_1) = 0{,}55$; $\mu_{special}(z_1) = 1$; $\mu_{training}(z_1) = 0{,}66$;
$\mu_{young}(z_2) = 0{,}77$; $\mu_{middle}(z_2) = 0{,}36$; $\mu_{old}(z_2) = 0{,}21$;
$\mu_{small}(z_3) = 0{,}54$; $\mu_{medium}(z_3) = 1$; $\mu_{big}(z_3) = 0{,}55$;
$\mu_{low}(z_4) = 0{,}2$; $\mu_{medium}(z_4) = 0{,}54$; $\mu_{high}(z_4) = 0{,}87$.

To determine the values of the membership function of the linguistic variables *H* "the quality of the components of the tactile surface", *P* "the quality of the formation of the tactile surface", and *Z* "the quality of the perception of the product content", we substitute the previously obtained values of the factors.

For the linguistic variable *H*, we get:

$\mu_{low}(H) = 0{,}33 \wedge 0{,}22 \wedge 0{,}25 \vee 0{,}33 \wedge 0{,}34 \wedge 0{,}5 = 0{,}33$
$\mu_{medium}(H) = 0{,}81 \wedge 0{,}22 \wedge 0{,}5 \vee 0{,}81 \wedge 0{,}34 \wedge 0{,}67 = 0{,}34$
$\mu_{high}(H) = 0{,}75 \wedge 0{,}78 \wedge 0{,}5 \vee 0{,}75 \wedge 0{,}78 \wedge 0{,}67 = 0{,}5$

The membership function of the linguistic variable *P* is:

$\mu_{low}(P) = 0{,}42 \wedge 0{,}55 \wedge 0{,}55 \vee 0{,}42 \wedge 1 \wedge 0{,}55 = 0{,}42$
$\mu_{medium}(P) = 0{,}63 \wedge 0{,}55 \wedge 1 \vee 0{,}63 \wedge 1 \wedge 0{,}45 = 0{,}55$
$\mu_{high}(P) = 0{,}77 \wedge 0{,}45 \wedge 1 \vee 0{,}77 \wedge 0{,}45 \wedge 0{,}66 = 0{,}45$

The linguistic variable *Z* gets the following values of the membership function:

$\mu_{low}(Z) = 0{,}55 \wedge 0{,}77 \wedge 0{,}54 \wedge 0{,}2 \vee 0{,}55 \wedge 0{,}77 \wedge 1 \wedge 0{,}2 = 0{,}2$
$\mu_{medium}(Z) = 1 \wedge 0{,}77 \wedge 1 \wedge 0{,}54 \vee 1 \wedge 0{,}36 \wedge 0{,}55 \wedge 0{,}87 = 0{,}54$
$\mu_{high}(Z) = 0{,}66 \wedge 0{,}21 \wedge 1 \wedge 0{,}54 \vee 0{,}66 \wedge 0{,}21 \wedge 0{,}55 \wedge 0{,}87 = 0{,}21$

Based on the calculated values of the membership functions of the linguistic variables *H, P, Z,* which determine the quality indicators of the isolated levels of the quality factors, we obtain the value of the membership function for the linguistic variable of the system level, which determines the integral quality indicator of TP image perception on the term-set {"low", "medium", "high"}.

$\mu_{low}(Q) = 0{,}33 \wedge 0{,}42 \wedge 0{,}2 \vee 0{,}33 \wedge 0{,}55 \wedge 0{,}2 = 0{,}2$;
$\mu_{medium}(Q) = 0{,}34 \wedge 0{,}42 \wedge 0{,}54 \vee 0{,}34 \wedge 0{,}55 \wedge 0{,}21 = 0{,}34$;
$\mu_{high}(Q) = 0{,}5 \wedge 0{,}45 \wedge 0{,}54 \vee 0{,}5 \wedge 0{,}45 \wedge 0{,}21 = 0{,}45$.

The calculation of the quantitative quality indicator of the image perception by people compared to the Blind people will be carried out on the basis of the centre of mass or centre of gravity method of a flat figure, which is limited by the graph of the membership function and the abscissa axis. This procedure is inverted to the fuzzification operation and consists in the de-fuzzification of a fuzzy set taking into account the values of the membership functions found.

The de-fuzzification of a linguistic variable is calculated by the formula:

$$Q = \frac{\sum_{i=1}^{m}\left[\underline{Q} + (i-1)\frac{\overline{Q}-\underline{Q}}{m-1}\right] \times \mu_i(Q)}{\sum_{i=1}^{m}\mu_i(Q)} \quad (2)$$

where: $\overline{Q}$, $\underline{Q}$ denote the minimum and maximum level of the quality of the TP image perception; m is a number of given fuzzy terms for LV Q.
We set the following values to the variables in the formula (2):

$$m = 3, \mu_1(Q) = \mu_{\text{low}}(Q), \mu_2(Q) = \mu_{\text{medium}}(Q), \mu_3 = \mu_{\text{high}}(Q).$$

We define the bottom and top limit for the linguistic variable Q, i.e. $\underline{Q} = 1\%$; $\overline{Q} = 100\%$.

We make the calculations for three dots of the set interval: 1%, 50%, 100%. Substituting the calculated values in the formula (2), we get:

$$Q = \frac{1 \cdot 0,2 + 50 \cdot 0,34 + 100 \cdot 0,45}{0,2 + 0,34 + 0,45} = 63\%.$$

The above method of calculating the prediction of the quality indicator of the tactile product perception is used for the experimental study.

6 Experiment

Modelling of the process components, a formalized description of the factors that characterize the process of the TP quality assessment, and determining the extent of their influence on the tactile surface perception provides a reasonable selection of parameters for the TP creation.

The information technology for the quality assessment of the tactile surface images perception is determined by a set of selection methods of reasonable parameters for TP manufacturing, a set of communication processes and program-technical means of the automation actions, integrated into the technological chain, which ensures the implementation of information processes in order to improve the reliability and efficiency with the reduction of complexity.

The structural and functional model of IT of the quality assurance of the image perception is presented in Fig. 1. The designed IT is set by five stages, each of which defines a separate action for the collection, analysis, modelling, synthesis of information to determine the quality of the tactile product perception by visually impaired people and the implementation of the expert-modelling calculation system of the quality indicator of the tactile product perception at the final stage.

In the first stage "Analysis of the subject area", a description of the components of the communicative process of Braille images perception by visually impaired people has been made, and the technologies of manufacturing a tactile information product

have been analysed. This procedure involves an analysis of the information tactile perception by visually impaired people with the identification of important factors and tools for tactile surface recognition in the first step. In the second step, the images of tactile products have been simulated. The final step of the stage describes the technology of tactile product manufacturing.

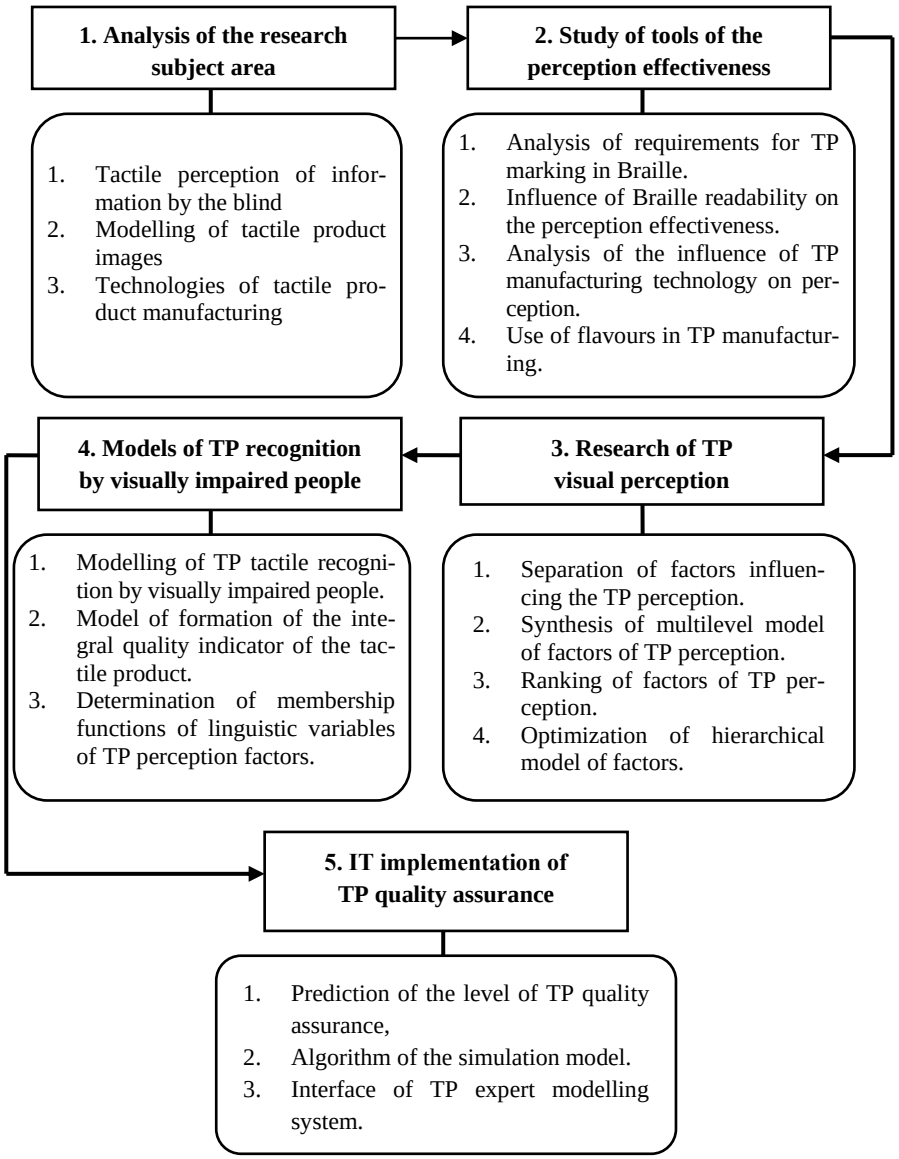

Fig. 1. Structural and functional model of IT of the quality assurance of the image perception

The aim of the second stage of IT "Study of tools of TP perception effectiveness" is to establish the requirements and dependencies that are applied to the components

of the communication interaction between Braille tactile surface and perception senses of the blind. This stage is accomplished through the following steps: the analysis of the requirements for TP marking in Braille; the influence of Braille readability on the perception effectiveness; the analysis of the influence of tactile production technology on perception; the use of flavours in TP manufacturing; the application of 3D technology for the production of Braille products.

The next, third stage of IT of the quality assurance of the image perception "Research of TP visual perception by the blind" is devoted firstly to the identification of expertly generalized factors influencing the TP perception. Next, a semantic network is formed as an oriented graph that reproduces the expertly established links between the factors of influence and identifies the influences and dependencies.

The next step is to synthesize a multilevel model of the priority influence of factors that influence the process of the quality assessment of the image perception by visually impaired people. Using the factor ranking method and taking into account the types, quantities and weight coefficients of the relationships between the factors, the factors rankings have been calculated and a refined multi-level model of their priority influence on the quality of tactile surface perception has been synthesized.

In order to establish the numerical values of the factors weights of the tactile product quality perception by the blind, an optimization of the multilevel model of factors has been carried out, which in the future will allow making sound decisions regarding the development parameters.

In the fourth stage of IT quality assurance "Models of TP recognition by the blind", the quality of tactile surface perception by means of fuzzy logic has been simulated. At the beginning, the formalization of the factors affecting the tactile product perception has been done by linguistic variables given by the term-sets, the values of the membership functions has been calculated for them on the basis of rank assessment for their formalization by fuzzy sets. The next step is to synthesize a hierarchical structure of interrelations between factors – a tree of logical inference is built to determine the quality of tactile products perception. Then, a knowledge base is designed using fuzzy logical statements of the type "IF <CONDITION>, THEN <CONCLUSION>", which reproduces the algorithm of the implementation of TP image quality perception depending on the quality level of linguistic terms. They are the basis for the logical equations that determine the relationship between the input and output data membership functions.

The final fifth stage of the "IT implementation of quality assurance" foresees the first step in predicting the level of TP quality assurance. It includes, based on the use of fuzzy logical statements of the type "IF <CONDITION>, THEN <CONCLUSION>", the logical inference of the value of TP image perception quality, depending on the quality level of linguistic terms. For automatic calculations, an algorithm for simulating the model of finding the quality indicator has been developed, which is implemented at the last step of IT of the practical implementation by constructing an expert-modelling system of technological products.

7 Results

The preliminary results of finding the quality indicator of the tactile product perception by the blind have made it possible to develop an algorithm for calculating the numerical value of the integral quality indicator and to design a simulation model based on it. The initial data for the construction of the simulation model are the following: a set of linguistic variables (isolated factors); a universal term-set of values of linguistic variables; term-sets of linguistic variables; knowledge matrices of linguistic variables of category H, P, Z; fuzzy logical equations for calculating the values of the membership functions of the linguistic variables; membership functions of term-sets of linguistic variables; the calculation of the numerical value of the de-fuzzification process of the fuzzy set Q in the form of a formula for calculating the quality indicator of the implementation of the book imposition. Here is a block diagram of an algorithm for calculating the value of the integral quality indicator of the tactile product perception (Fig. 2).

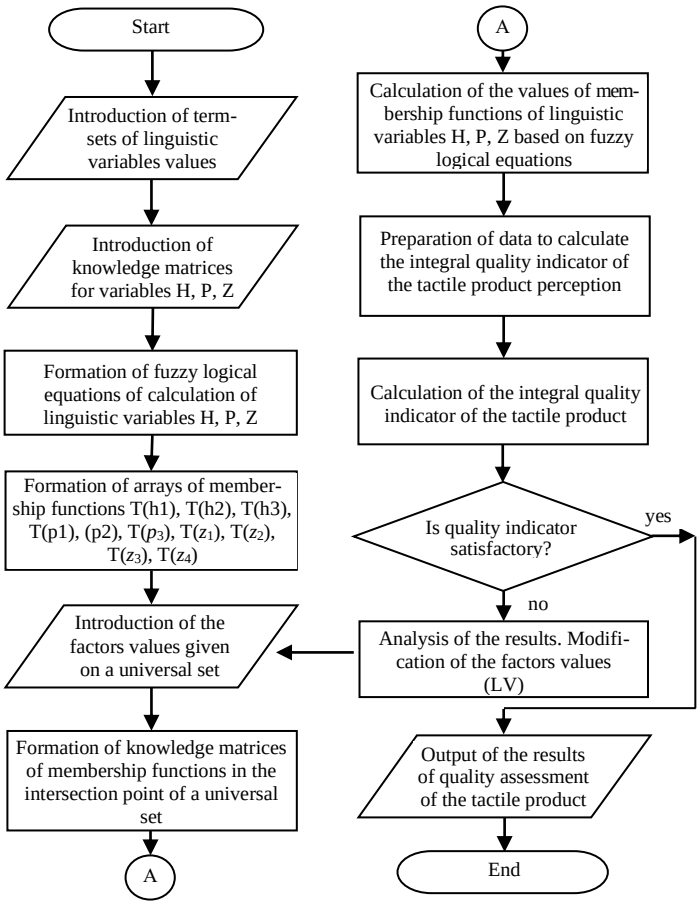

Fig. 2. Block diagram of the algorithm for calculating the value of the integral quality indicator of the tactile product perception

The algorithm reproduces the general logic of the program component functioning, which consists in performing the following procedures: the introduction of elements of the universal set, which relate to the intervals of the possible values of the factors (linguistic variables) of the lowest level; the introduction of a knowledge matrix related to categories; the introduction of technological parameters of the factors given by the universal term set; the formation of arrays of membership functions and matrices with normalised values of membership functions at the points of interval separations of linguistic variables parameterization; the calculation of the integral quality indicator of the imposition process; the analysis of the results and making decisions whether to terminate or continue the program.

According to the above algorithm, the program "Calculator of the tactile product perception quality" has been designed, which on the basis of the procedures described above, through a visual dialogue with the user, provides the calculation of the quality of the tactile product perception of a given quality using the suggested interface (Fig. 3).

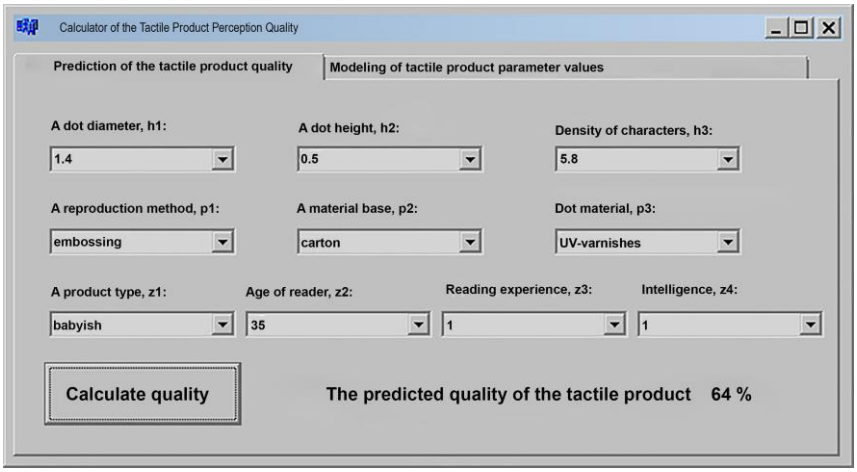

Fig. 3. The interface of the program "Calculator of the tactile product perception quality" of the problem "Prediction of the tactile product quality"

As you can see from the figure above, the program window "Calculator of the tactile product quality" contains two tabs "Prediction of the tactile product quality" and "Modelling of the parameters values". The first tab provides the main purpose of the program, namely, the input of the initial data of the influence factors and the output of the values of the predicted quality of the tactile product. The second tab allows one to solve the inverse problem of modelling of the tactile product. It happens this way. The values of the factors of the surface geometry: "a dot diameter", "a dot height", "density of characters"; the factors of perception of the tactile product content: "a product type", "age of reader", "reading experience", "intelligence" and the expected level of "tactile product quality" are set. On their basis, the program calculates the variants of the factors values of the tactile product surface parameters: "a reproduction method", "material-base" and "material for dot formation".

The simulation model "Calculator of the tactile product quality" implemented by a program means can be used as an expert-modelling system to make decisions on the parameters for designing a tactile product of the proper quality.

Summarizing the results, it can be stated that the aim of the study, which was to design the information technology to ensure the quality of the image perception by blind people, has been achieved.

8 Conclusions

The implementation of the information technology has been done to ensure the quality of the image perception by the blind, which is determined by a set of selection methods of reasonable parameters for the tactile product manufacturing, a set of communication processes and program-technical means of automation actions, which ensures the implementation of information processes to improve the reliability and reduce the complexity.

As a result, a structural and functional model of the information technology for quality assurance of the image perception has been constructed, which is defined in five stages, each of which reveals a separate action regarding the collection, analysis, modelling, synthesis of information to determine the quality of the tactile product perception by visually impaired people and the implementation of calculation of the perception quality indicator by the expert-modelling system at the final stage. An algorithm and a simulation model have been developed for calculating the value of the integral quality indicator of the tactile product perception in the form of an expert-modelling program "Fuzzy controller for predicting the quality of tactile products".

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