INFORMATIONAL-PARAMETRIC MODEL OF SIGN LANGUAGE FINGERSPELLING UNITS

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Résumé: An approach for researching fingers' movement with an aim to create a formal notion of sign language fingerspelling units (dactyls) is considered. Then an informational parametric model of a human arm is suggested that describes possible movements during fingerspelling process. 10 fingerspelling alphabets are analyzed mutually compared for exact and partial similarity as well as notable distinctions. The example of a .Net-based software application is then provided that teaches proper Ukrainian fingerspelling.

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ACM Classification Keywords: *I.2.8 Problem Solving, Control Methods, and Search H.1.1 Systems and Information*

Introduction and problem statement

The rapid development of computing and creation of new methods for data representation, storage and organization makes it possible to innovate and create new technologies in the field of analysis of communication in sign language and modeling thereof. [1]. From the practical point of view, teaching systems of sign language that use 3D human model are very promising. Since the information is transmitted by the mean of arms movements, mimics and articulation it is necessary to research the process of construction of a sign language sentence as well as the synthesis of the elements in order to get a good understanding of the subject. The problem of description of human movements is complex enough with a high percentage of fuzzy knowledge about human body and its physiology. From the linguistic viewpoint, the problem is considered in a vast amount of research works, e.g, [2], [3] et al. Among language specification systems, *Hamburg Notation System* [4] stands apart, as it includes various graphical signs and therefore allows to describe a large set of gestures. The system *SignWriter* [5] got a wide range of applications as it uses textual signs alongside graphical ones. This kind of signs is not always suitable for modeling purposes since the information requires equivalent counterparts in data structures. Therefore it is important to conduct a research of the process of how the gestures are formed from the viewpoint of formalization for the problem of modeling using 3D model and for the problems of gestures analysis and synthesis.

This work pays the primary attention to research of fingers movement since they play primary role in the fingerspelling process. The essence of the problem is to reconstruct the information about a gesture for the visual reproduction on a 3D model of human palm based on the textual description. The complexity of the problem is that the verbal description of a dactyl (fingerspelling unit) combined with photo and video materials do not fully define the special positions of the dactyl and therefore the question of how the fingers are positioned may be hard to answer. It is therefore necessary to create such a notion of a dactyl that would unambiguously define the position of every finger and the dactyl. The other problem no sign language speaker learns the exact dactyls, but introduces his or her tiny variations. Therefore, there is not "right" etalon of a dactyl. Therefore it is necessary that created hand models and corresponding animation would satisfy the standard of fingerspelling. The creation of informational parametric model of a hand should take into account the standard but ignore the variations that do not change the meaning. For example, the degree of a finger's curvature would vary with speakers, but this does not involve that there are as many ways of showing the same dactyl. Conclusively, the problem is to denote the formal description of a dactyl and create its visual animated representation on a 3D human's hand model. The purpose of this work is to analyze fingerspelling alphabets and a formal notion of a dactyl for the problem of modeling the human movements using informational 3D model and further synthesis of dactyl information and for the creation of computer-based fingerspelling teaching technologies.

Analysis and formalization of fingerspelling alphabet based on natural parameters

Parameters of a dactyl's structure. W.Stokoe determined three parameters that describe the structure of a gesture: the position of a gesture, the hand shape (its configuration and orientation) and the movement [2]. Based on the classification, three main parameters were determined and were used to analyze dactyls:

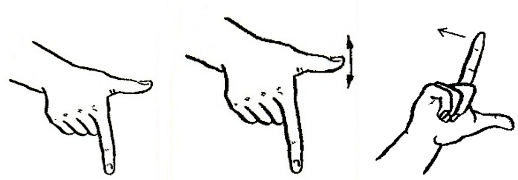
1. Fingers configuration,
2. Orientation of a hand in space,
3. Type of the movement.

Special attention is paid to the study of a hand configuration because in the process of constructing three-dimensional model of the human hand, the key moment is to determine the correct configuration of the fingers and then to determine a location of the hand in space and the kind of motion. At this stage, hand position in space relatively to the speaker is not taken into account, it is believed that the hand is an object in a space. To build the specifications of fingerspelling units of a sing language the following parameters were used: fingers configuration, hand orientation, and hand movement.

Fingers configuration is a set of the following parameters: a set of fingers involved in the letter construction; fingers configuration (the degree of the slope, curvature); mutual disposition.

Preserving generosity, let's demonstrate the process of building of informational-parametric model of dactyls visualization Ukrainian fingerspelling alphabet. Ukrainian fingerspelling alphabet consists of 33 letters and 24 of them have a distinct corresponding fingers' configuration (А, Б, В, Г, Е, Є, Ж, З, И, І, Л, М, Н, О, П, Р, С, Т, У, Ф, Х, Ч, Ю, Я). For the other 9 letters, the corresponding fingers' configuration is similar and differ from the previous by a hand orientation (e.g. Ш) and/or by the movement (e.g. Ь, Ї, К). Other fingerspelling alphabets have a similar structure. The example is shown in the Table 1.

Table 1. Dactyls that share fingers' configuration but differ in hand orientation and movement.

Letters	Hand configurations
Г – Ґ – Ь	

Informational-parametric model of fingerspelling units

Informational-parametric model of fingerspelling units is an ordered triple {*K, O, M*}, where parameter *K* describes fingers' configuration, *O* describes hand's orientation in space, *M* describes the movement.

Parameter *K* is an ordered sextuple {f_1, f_2, f_3, f_4, f_5, *c*}, where parameters f_i, $i = \overline{1,5}$ describe a configuration of each finger separately, specifically configurations of: f_1 – thumb, f_2 – pointing finger, f_3 – middle finger, f_4 – ring finger, f_5 – little finger, *c* is a relation between fingers except thumb, which are used for building dactyl.

Meaning of the parameter f_1 (thumb finger) is shown in the Table 2.

Table 2. Meaning of the parameter f_1

Meaning	Description	Example
1	Straight	A (Ukrainian)
2-α	Deflects in a plane of the palm on α degrees	Г (Ukrainian)
3-1	Over fist (or over a few fingers)	Я, I (Ukrainian)
3-2	Over pointing finger	
3-3	Over middle finger	P (Ukrainian)
3-4	Over ring finger	H (Ukrainian)
3-5	Over little finger	T (Ukrainian)
4	In the middle of a fist (or on a palm)	B, X (Ukrainian)
5-0	Forms an arc with other fingers (not closed arc)	C (Ukrainian)
5-1	Forms an arc with other fingers (closed arc)	O (Ukrainian)
5-2	Forms crossing with a finger	T (Polish)
6	Horizontally, props fingers	E (American)
7-3	Abuts on a middle finger by finger-pad	T (American)
7-4	Abuts on a ring finger by finger-pad	N (American)
7-5	Abuts on a little finger by finger-pad	M (American)
8	Parallel to the palm plane	K (American)

Other parameters vary as follows: f_i = $x\,[\,y\,]$, $i = \overline{2,5}$, where $x \in [0,1]$, $y \in [0,1]$. Here x denote the degree of the slope of the *i-th* finger relatively to the flat state ($x = 1$), y – the degree of curvature of a finger (parameter y can be skipped in description).

Flat state ($x=1$) is equivalent to the letter «B»'s hand configuration (all fingers are straight and in the plane of the palm). Close state ($x=0$) is equivalent to the letter «A»'s hand configuration (fingers are bent into a fist).

Parameter *c* is defined as follows:

$$c = \begin{cases} 0, \text{ if only 1 or 0 fingers involved,} \\ 1, \text{ if fingers (2 or more) raised up and touch to each other,} \\ 2, \text{ if fingers don't touch each other,} \\ 3, \text{ if fingers are one above the other (letter «Я»),} \\ 4, \text{ if fingers are shifted in diffferent planes (letter «Б»).} \end{cases}$$

An example of defining the specifications for fingers' configuration is listed in the Table 3.

Parameter *O* is an ordered triple *{α, β, γ}*, where *α, β, γ* denote angles of a hand rotation in space relatively to the initial state.

Initial state is defined as hand orientation *O {0,0,0}* . When fingerspelling letter «B», hand rotates with angle $\alpha = 180^\circ$ i.e. with palm facing the viewer.

Table 3. Specification of fingers' configuration.

Letter	F_1	f_2	f_3	f_4	f_5	*c*	Configuration
Х	4	0	0	0	0,2 [0,2]	0	
К	3-1	0	0	1	1	2	
Е	5-1	0,5 [0,5]	0,5 [0,5]	0,5 [0,5]	0,5 [0,5]	1	
Я	3-1	0	0	1	1	3	

Parameter *M* describes the type of a movement. At this stage of the making specification, parameter of movement is described as follows:

$$M = \begin{cases} 0, \text{ no movement,} \\ 1, \text{ movement is made by some part of a hand (e.g. «Ґ»),} \\ 2, \text{ movement is descriptive(e.g. «З», «Д»),} \\ 3, \text{ shift in a spacec, rotation, slope (e.g. «К», «Щ»),} \\ 4, \text{ transition from one fingers' configuration to another one.} \end{cases}$$

Based on these parameters, the table of specifications with 12 parameters is built (see Table 4).

Table 4. An example of specifications.

Language	Letter	f_5	f_4	f_3	f_2	f_1	c	α	β	γ	M
Ukrainian	У	1	0	0	0	2-45	2	180	0	0	0

Given formal notion is informative and easy enough for perception in the context of movement modeling. It is quite easy to build specifications for other manual alphabets using the notion.

Analyses of fingerspelling units with the help of specification system

Similarly to the analysis of Ukrainian fingerspelling alphabet, analyses of other fingerspelling alphabets have been made and the tables of specifications for American, German, French, Polish, Russian, Greek, Japanese, Spanish, Swedish fingerspelling alphabets have been built. The general analysis of abovementioned fingerspelling alphabets makes it possible to build such a formal specification that allows to describe not only Ukrainian fingerspelling alphabet, but also other one-handed manual alphabets. For instance, the result of similarity analysis of each fingerspelling alphabet is shown in Table 5.

Table 5. Results of research on similarity of the fingerspelling alphabets

Fingerspelling alphabet	Number of letters	Number of configurations	Fingerspelling alphabet	Number of letters	Number of configurations
Ukrainian	33	24	French	26	21
American	26	23	Swedish	29	20
Polish	32	19	Japanese	46	27
Russian	33	24	Spanish	30	20
German	30	23	Greek	24	20

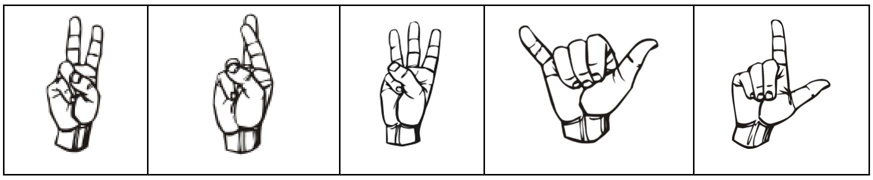
Based on the obtained specifications a comparative analysis of the Ukrainian manual alphabet with other sign languages manual alphabets was performed. Parameters of fingers configurations defined earlier in this paper were used for the comparison. Herewith we ignored hand orientation and movement since any letter can be obtained by constructing fingers' configuration, determine hand orientation in a space and movement. The results of analysis that show equal dactyls are listed in Table 6.

Table 6. Results of the comparison of the fingers' configurations fingerspelling alphabets. Legend: 1 – number of unique configurations for particular fingerspelling alphabet; 2 – number of configurations that coincide with set of 24 distinct configurations of Ukrainian fingerspelling alphabet.

Alphabet	1	2	Alphabet	1	2
American	23	12	French	21	10
Polish	19	11	Swedish	20	11
Russian	24	21	Japanese	27	13
German	23	13	Spanish	20	12
Greek	20	10			

Also the comparative analysis of each alphabet with another one was made. Can be determined that three configurations (Л, М, Я) are common for all ten fingerspelling alphabets. Such configurations as Л, Я, М, У, Г are common for 10 alphabets (see Table 7).

Table 7. Fingers' configurations that are common for 10 manual alphabets.

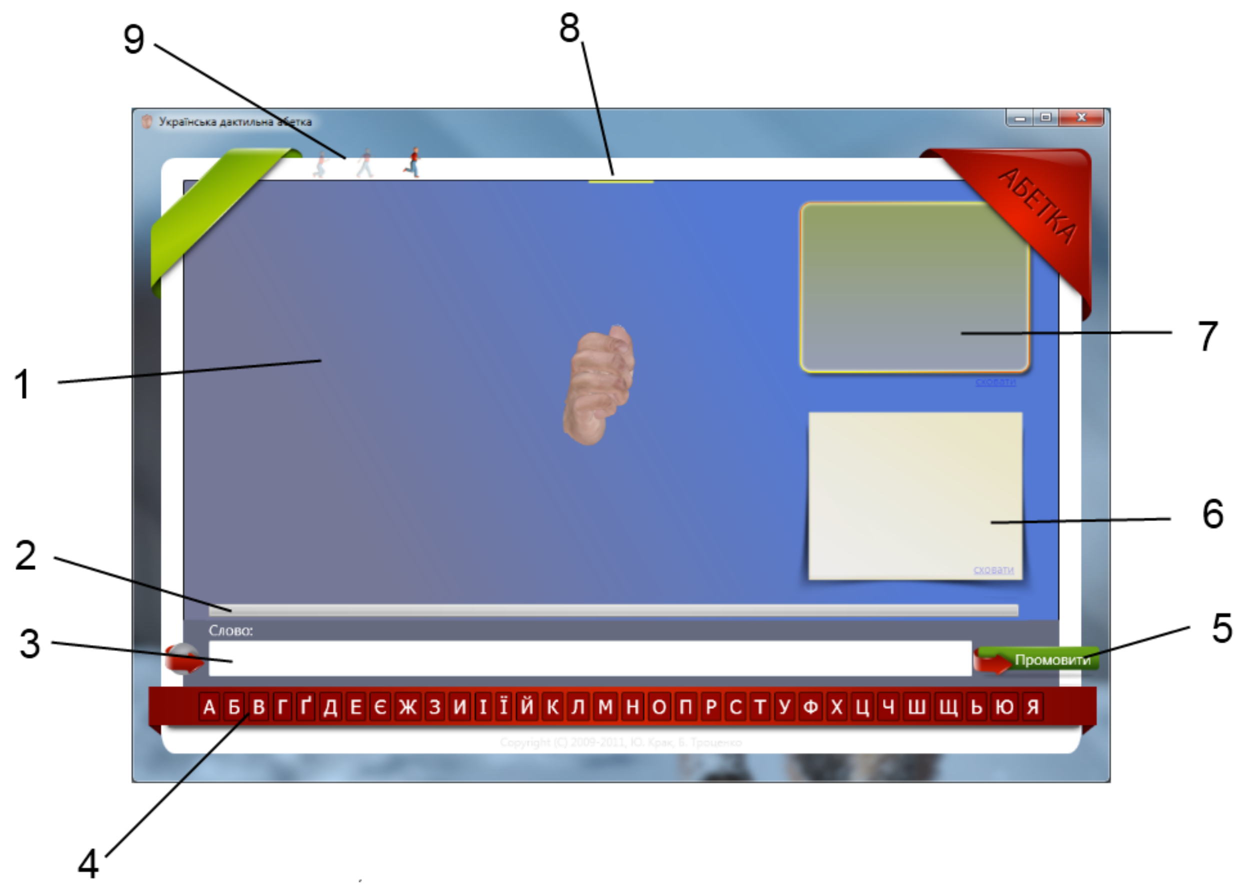


An analysis of ten fingerspelling alphabets were performed. 309 letters (dactyls) of 10 sign languages fingerspelling alphabets were analyzed. 221 is the sum of number of unique configurations for each fingerspelling alphabet. From the set of 221 configurations only 59 are unique configurations. Denote this set by U. It follows that any letter from the 10 fingerspelling alphabets analyzed can be uniquely obtained from the set U, changing the orientation of the hand in a space and/or adding movement.

Thus, we can conclude that it is possible to build set of models of human hand, which will identify precisely the fingers' configurations for manual alphabets of Ukrainian, Russian, Polish, Greek, American, German, French, Spanish, Swedish, Japanese sign languages.

Software implementation of modeling of a three-dimensional model of a hand and animation of fingerspelling process

To teach fingerspelling, technology that uses a three-dimensional model of a hand based on a informational-parametric model has been developed. The technology allows to observe hand from different viewpoint during the learning process, show sequence of letters etc. The main window is shown on a Picture 1.



Picture 1. The main window of a program «Ukrainian fingerspelling alphabet».

At this point the numbers mean: 1 – area of displaying fingerspelling alphabet; 2 – panel of displaying playback progress of letters or words; 3 – input panel for words; 4 – list of letters; 5 – button «spell», the process of fingerspelling of input word begins when the button is clicked; 6 – panel to display the verbal description of a hand configuration that correspond to the current displayed letter; 7 – panel to display written letter and a picture that correspond to the current displayed letter; 8 – indicator of a location of a hand rotation; 9 – define the pace of fingerspelling.

The main features of the program:

1. Changing of a view angel. The use of a three-dimensional modeling enables the possibility to examine hand model from different viewpoints. That would be impossible using video materials. The range of changing an angle of viewpoint vary to 80° right/left.

2. Presence of pictures which are associated with particular letter for whole alphabet (see Picture 2) (this panel can be hidden and shown back).

Picture 2. Working examples of fingerspelling letters “O” and “X”, respectively.

3. Verbal description of hand configuration which is shown.

4. Presentation of dactyls is performed by selecting a particular letter from a list using mouse or by pressing letter-button on a keyboard. If user wants to repeat, press space. This feature allows to implement interactive learning process, when thee right arm (trained) is in the free position and the left realize interactions with the program.

5. Changing the pace of the animation. Three pace modes (slow, medium, fast) are implemented in the program for the different needs of the learning process (repetition after the model, recognition of the foregoing, etc.).

6. Fingerspelling of a word. This feature allows entering words into input panel and observing process of fingerspelling of a word. That allows not only learn separate letters but also learn how to spell whole words.

7. Verification mode. The program has a feature to “hide” the panel of the verbal description of a hand configuration and the panel with written letter and a picture. That allows conducting examination of knowledge displayed letter (hand configuration).

Based on this technology, training programs for any one-handed fingerspelling alphabet can be created. There are currently developed programs for Ukrainian, Russian, Polish and American fingerspelling alphabets.

Conclusion

The resulting information-parametric model allows to effectively build specifications for different fingerspelling alphabets. Investigation of Ukrainian fingerspelling alphabet in this work contributes to the development of technologies for the building of computer technologies of training Ukrainian fingerspelling alphabet. Construction of specifications of fingerspelling alphabets of different sign languages and their comparative analysis are the basis for the development of training systems of fingerspelling alphabet for different sign languages. Developed technologies in the field of three-dimensional modeling and animation of human gestures have shown their efficiency in training Ukrainian fingerspelling alphabet. The universality of this technology allows creating various training programs of fingerspelling alphabets.

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