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A GN model for on-line signature verification

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Abstract: In this paper, a generalized net model for a combined method for on-line signature verification is proposed. The model describes all the necessary steps in developing a signature recognition system: signature data pre-processing, feature extraction and selection, verification and system evaluation.
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1 Introduction

Signature verification is the process of confirming the identity based on the handwritten signature of the user as a form of behavioral biometrics [11]. From one hand, the signatures are a convenient, widely used and secure mean for authentication, and from the other, their input to biometric systems is fast, easy, natural and non-invasive. For these reasons, the problem of the signature verification is broadly investigated in the past years. Novel methods and algorithms are developed, mostly for on-line signatures, and lots of them are implemented in practice [5, 7, 12]. On-line signature verification systems use devices such as graphical tablets to capture signature during signing and thus a lot of writer specific features like pressure, speed, pen tilt, azimuth, etc. are available [9].

The Generalized Nets (GNs) [1] are an extension of Petri Nets used for modeling of different processes. For example, in [2] a supposition that GNs can be used as a universal tool for modeling of intellectual processes, i.e. processes that could be associated to the domain of AI is made. In a series of papers in the book [4], various processes of the field of pattern recognition are modeled by GNs. In this paper, we aim to detail the process of on-line signature verification by extending the model presented in [3].

This paper is organized as follows. In Section 2 a brief overview over the combined on-line signature verification method is given. Short remarks on generalized nets are considered in Section 3. Next, the GN model is presented in Section 4. Finally, Section 5 concludes the paper.

2 A combined method for on-line signature verification

For each user of the database, we construct a NN model for verification. With regard to this we perform the following steps. At the pre-processing stage, some transformations are performed on the signatures (coordination transformation, rotation and translation)in order to facilitate feature extraction. Since some features demonstrate higher discriminatory capability than others, feature selection should be performed. This is related to the process of selecting k features of most discrimination power out of p available ones ($k \leq p$) and it aims to identify and remove as much irrelevant and redundant information as possible. Next, we extract signature features and perform feature set selection by applying the method for selection of regression variables based on *Mallows Cp* criterion [6, 8] to identify best feature subset. After that step, we construct NNs of varying size of hidden neurons and we perform cross-validation in order to choose the best performed one of them. Such selected model is defined by the following parameters: number of hidden neurons and input features. Finally, we train, validate and test all the chosen user's models and use them for further verification.

A particular NN is built for each user on the basis of his/her genuine and forgery signatures. The number of input neuron is p where p is the number of the features. The single output neuron has a value *1* for genuine signature and a value *0* for forgery signature. After the training, a score threshold is determined. If the verification result (at the time of testing of a signature) is greater than the corresponding score threshold, the signature is considered genuine, otherwise – forgery. This approach is widespread because it allows fast adding and deleting of signatures for new and existing users [10]. Usually, NN training takes lots of time but in this approach it is done off-line so the users are not forced to wait.

3 Generalized net model

The constructed reduced GN is presented in Fig. 1. For this model tokens keep all their history. The transition condition predicates and token characteristics are described not absolutely formally in order to make easier the understanding of the formalism in use.

The model is built of six transitions Z_i, $i = 1, \ldots, 6$, which correspond to the steps in on-line signature verification, twelve places and three types of tokens α, β and γ.

Initially, α-token enters in place L_1 with initial characteristics"*an on-line signature"*. There is a β-token in place L_7 with initial and current characteristics "*feature subset from the signature DB"* at the time of the functioning of the model. All the tokens entering L_7 merge with the original β-token. There is a γ-token in place L_{12} with initial characteristics "*saved NN model for the current user*" at the time of the functioning of the model. All the tokens entering L_{12} merge with the original γ-token.

For the sake of brevity we shall denote α, β, γ-tokens and not use indexes indicating the current token's number.

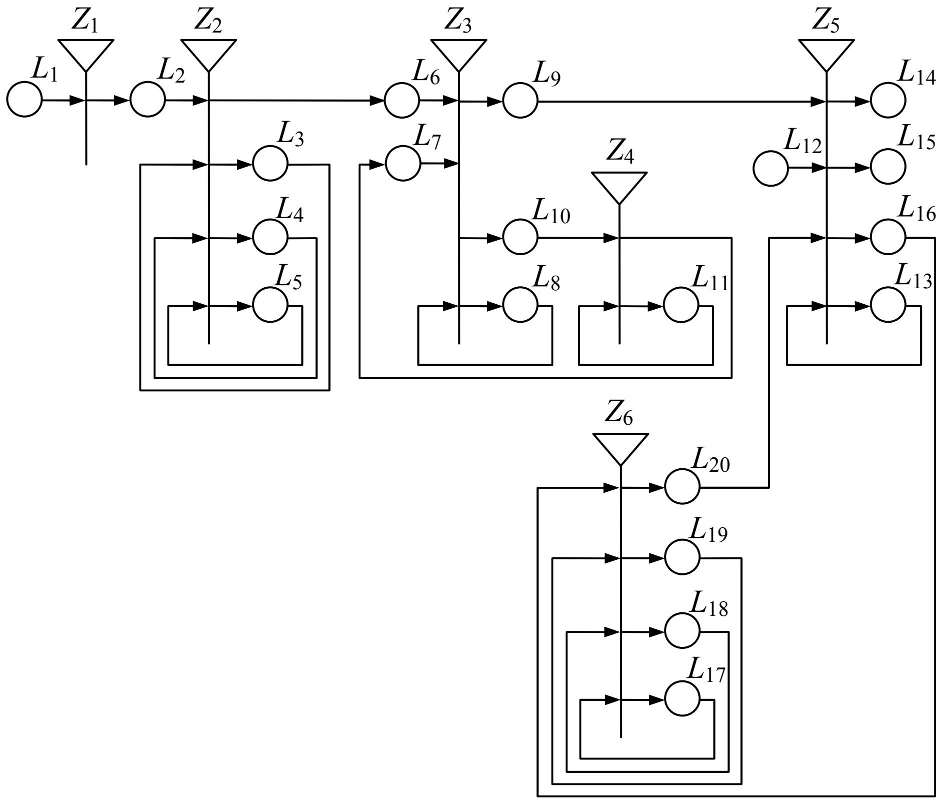

Figure 1. GN model for on-line signature verification

Transition Z_2 describes pre-processing stage, which includes the following steps: coordinate transformation, rotation and translation.

$$Z_2 = \langle \{L_2, L_3, L_4, L_5\}, \{L_3, L_4, L_5, L_6\}, r_2, \vee(L_2)\rangle,$$

$r_2 =$

	L_3	L_4	L_5	L_6
L_2	*true*	*false*	*false*	*false*
L_3	$W_{3,3}$	$W_{3,4}$	*false*	*false*
L_4	*false*	$W_{4,4}$	$W_{4,5}$	*false*
L_5	*false*	*false*	$W_{5,5}$	$W_{5,6}$

The predicates associated with the transition have the following meaning:

- $W_{3,4}$ = "Coordinate transformation is performed".
- $W_{3,3} = \neg W_{3,4}$.
- $W_{4,5}$ = "Rotation is performed".
- $W_{4,4} = \neg W_{4,5}$.
- $W_{5,6}$ = "Translation is performed".
- $W_{5,5} = \neg W_{5,6}$.

The α-token obtains the characteristics "*Signature data is pre-processed*" at place L_6.

Transition Z_3 is related to signature feature extraction.

$$Z_3 = \langle \{L_6, L_7, L_8\}, \{L_8, L_9, L_{10}\}, r_3, \wedge(L_7, \vee(L_6, L_8))\rangle,$$

$$r_3 = \begin{array}{c|ccc} & L_8 & L_9 & L_{10} \\ \hline L_6 & W_{6,8} & false & W_{6,10} \\ L_7 & W_{7,8} & false & false \\ L_8 & W_{8,8} & W_{8,9} & false \end{array}$$

The corresponding user features are obtained from the signature database. Therefore a new β-token enters place L_7 with initial characteristics "*Feature subset obtained from the database*". Features are calculated at place L_8.

Predicates associated with the transition have the following meaning:

- $W_{6,8} = W_{7,8}$ = "There exists a feature subset for the user in the database".
- $W_{6,10} = \neg W_{6,8}$.
- $W_{8,9}$ = "All the feature values (from the common and individual feature subsets) are calculated".
- $W_{8,8} = \neg W_{8,9}$.

The α-token from place L_6 merges with β-token from place L_7 in a new α-token at place L_8. The α-token at place L_9 obtains a characteristic: "*All the necessary feature values are extracted*", and at place L_{10} a characteristics: "*Feature selection is has not been performed yet*".

Transition Z_4 is related to the feature selection of common and individual feature subsets and their save in the database:

$$Z_4 = \langle \{L_{10}\}, \{L_{11}\}, r_4, \vee(L_{10}) \rangle,$$

$$r_4 = \begin{array}{c|cc} & L_7 & L_{11} \\ \hline L_{10} & true & false \\ L_{11} & false & true \end{array}$$

The α-token at place L_{10} obtains a characteristic "*Feature selection is performed from DB in place L_{11}*" and it merges with the original β-token at L_7.

Transition Z_5 describes the verification by using a neural network. If there exist a stored NN for the user, it is tested with the values of the corresponding features. The claimed identity is accepted if the output of verification exceeds the corresponding threshold value, and it is rejected otherwise.

$$Z_5 = \langle \{L_9, L_{12}, L_{13}\}, \{L_{13}, L_{14}, L_{15}, L_{16}\}, r_5, \wedge(L_{12}, \vee(L_9, L_{13})) \rangle,$$

$$r_5 = \begin{array}{c|cccc} & L_{13} & L_{14} & L_{15} & L_{16} \\ \hline L_9 & W_{9,13} & false & false & W_{9,16} \\ L_{12} & W_{12,13} & false & false & false \\ L_{13} & false & W_{13,14} & W_{13,15} & false \\ L_{20} & W_{20,13} & false & false & false \end{array}$$

New γ-token enters place L_{12} with initial characteristics "*Saved NN model for the user*". The predicates associated with the transition have the following meaning:

- $W_{9,13} = W_{12,13} = W_{20,13}$ = "There exists a NN model for the user".
- $W_{9,16} = \neg W_{9,13}$.
- $W_{13,14}$ = "Testing the NN model: The identity is accepted".

- $W_{13,15}$ = "Testing the NN model: The identity is rejected".

The token at place L_{14} obtains characteristics "*The identity is accepted*". The token at place L_{15} obtains characteristics "*The identity is rejected*". The token at place L_{16} preserve all its characteristics.

Transition Z_6 describes different NN modes testing, NN model and parameter selection and NN training. The optimal NN model is selected by performing a cross validation procedure. That model is kept together with the corresponding feature subset and threshold.

$$Z_6 = \langle \{L_{16}, L_{17}, L_{18}, L_{19}\}, \{L_{17}, L_{18}, L_{19}, L_{20}\}, r_6, \wedge(L_{16}, \vee(L_{17}, L_{18}))\rangle,$$

$$r_6 = \begin{array}{c|cccc} & L_{17} & L_{18} & L_{19} & L_{20} \\ \hline L_{16} & true & false & false & false \\ L_{17} & W_{17,17} & W_{17,18} & false & false \\ L_{18} & W_{18,17} & true & W_{18,19} & false \\ L_{19} & false & false & false & true \end{array}$$

The predicates associated with the transition have the following meaning:

- $W_{17,17}$ = "is necessary a NN model having number $s + 1$ to be built, s being the number of cycles of the token at that place, $s < N$, N being total number of the models".
- $W_{17,18}$ = "NN model built at step $s+1$ is not cross validated, s is the number of cycles of the token at that place".
- $W_{18,17}$ = "$s < N$".
- $W_{18,19} = \neg W_{18,17}$.

Tokens entering place L_{18} obtain the characteristics "*Evaluation of the current NN model by cross validation*". Token entering place L_{19} obtains the characteristics "*The best performed NN model is chosen by cross*". Token entering place L_{20} obtains the characteristics "*The best performed NN model is trained and saved*" and merges with the γ-token at place L_{12}.

5 Conclusion

The GN formalism proves to be a suitable tool to model different processes. It allows for an easy presentation and evaluation of the properties of processes. The described model for on-line signature verification can be included as a sub-net in a larger scheme for biometric authentication.

References

[1] Nalwa, V.S., I. Ekeland, Automatic on-line signature verification. *Proceedings of the IEEE 85*, 1997, 213–239.

[2] Atanassov, K. *Generalized Nets in Artifficial Intelligence. Vol. 1: Generalized nets and Expert Systems.* "Prof. M. Drinov" Academic Publishing House, Sofia, 1998.

[3] Jain, A., Stan Li. Encyclopedia of Biometrics, Springer, 2009.

[4] Atanassov, K., *Generalized Nets*, World Scientific, Singapore, 1991.

[5] Hocking, R. R., R. Leslie. Selection of the Best Subset in Regression Analysis. *Technometrics*, Vol. 9, 1967, 531–540.

[6] LaMotte, L. R., R. R. Hocking. Computational Efficiency in the Selection of Regression Variables. *Technometrics*, Vol. 12, 1970, 83–93.

[7] Atanassov, K., G. Gluhchev, S. Hadjitodorov, J. Kacprzyk, A. Shannon, E. Szmidt, V. Vassilev. *Generalized Nets Decision Making and Pattern Recognition*. EXIT Publishing House, Warsaw School of Information Technology, Warszawa, 2006.

[8] Gluhchev, G., M. Savov, O. Boumbarov, D. Vassileva. A New Approach to Signature Based Authentication", *Proc. of 2nd Int. Conf. on Biometrics*, Seoul, 26–29 August, 2007, 594–603.

[9] Savov, M., G. Gluhchev. Signature verification via Hand-Pen motion investigation. *Proc. Int. Conf. "Recent Advances in Soft Computing"*, Canterbury, 2006, 490–495.

[10] Atanassov, K., G. Gluhchev, S. Hadjitodorov, A. Shannon, V. Vassilev, *Generalized Nets and Pattern Recognition*. KvB Visual Concepts Pty Ltd, Monograph No. 6, Sydney, 2003.

[11] Leclerc, F., R. Plamondon. Automatic signature verification: The state of the art 1989–1993. *International Journal of Pattern Recognition and Artificial Intelligence*, Vol. 8, 1994, No. 3, 643–660.

[12] McCabe, A., J. Trevathan, W. Read. Neural network-based handwritten signature verification. *Journal of Computers*, Vol. 3, 2008, No. 8, 9–22.