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Relations between features for automatic recognition of abnormal cases in emergency telephone call systems

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Abstract— **This paper presents the use of relations between features, which describe a caller for automatic recognition of abnormal cases in emergency telephone call systems. The proposed correlation based procedure, as an integral part of the authors' advanced database search mechanism dedicated to emergency notification centers, extends the record matching procedures and takes into account dependences between features. Illustrative examples and experiments show that the presented procedure significantly improves recognition of impossible cases, e.g. those reported by cheaters.**

Keywords-emergency telephone system; automatic speaker recognition; metadata; correlation matrices

I. INTRODUCTION

Emergency Notification Centers (ENC) are very commonly used, but register also a significant number of false and hoax calls. For example in ENC for Poznan city (Poland) more than 75% of all notifications are of such type [1]. In big cities there are thousands of notification per day, often many of them related to the same event, it is not easy to infallibly send appropriate rescue units in order to defeat a threat. The most important issues in ENCs are related to recognition of:

- multiple reports of the same threat event
- reports from the same speaker
- speakers who may be unreliable [2].

Approaches to solve these issues are under scientific investigations [3, 4]. Recognition process can be characterized by distinct description based on metadata [4]. The most important metadata, selected from many features that come from a call, should be analyzed [5, 6]. In fact, the solutions of presented problem are not very common. We found only one similar to our system of intelligent ENC management [7]. It uses the Kohonen Self Organizing Map, which searches the calls related to an anomalous situation. Only three source features were taken into account: a time of the call, class of the call and the region of an incident. With the use of these features, some derivative features were calculated. As example 25.000 calls were analyzed to find relations with Emma hurricane, the results were given on the maps, with no other numerical results.

In the presented solution of the recognition problem much more features have been used. In the authors' opinion even more than 30 significant features can be taken into consideration. These features describe event type and category, its place, i.e., the city name, street, acoustic background and basic caller data including gender, age, speaking features, etc. The data may be collected directly by the telephone operator, may be available from the telephone services, or can automatically be generated from the audio files.

During the recognition process, parameters of features in a current (reference) conversation are compared with the corresponding attributes of the conversations stored earlier in the database. The features f may be compared using binary matching (features set F_B), numerical matching (features set F_N), term based matching (features set F_T), and correlations (features set F_C). The results of comparisons give partial matching scores [8, 9]. The final score S is a sum of the partial matching scores v_B, v_N, v_T, v_C, weighted by coefficients w_f:

$$S = \sum_{f_j \in F_B} w_f v_B(f_j) + \sum_{f_j \in F_N} w_f v_N(f_j) + \sum_{f_j \in F_T} w_f v_T(f_j) + \sum_{f_j, f_k \in F_C, f_j \neq f_k} w_{f_j f_k} v_C(f_j, f_k) \quad (1)$$

Records with high values S are considered to be the most similar to the reference record. The resulting records are sorted by decreasing the matching order and presented to the operator. More detailed description of this comparison mechanism is presented in [2, 8, 9].

Beside the basic comparison of features, the mechanism can also take the dynamics of features into account. For example, one feature may be influenced by another feature, e.g. age of the caller is changed by the passage of time. These dependences are referred to as the correlations [10]. Another example is the detection of the caller's movement. The caller who reported two events located very distantly in a short time should be recognized as a cheater (the reported facts cannot all together be true). In the age of mobile phones there are many possibilities of possible caller's location. Using data from the telecommunication network it is possible to plot the travel trajectory [11]. However, the proposed correlations, as a part of the speaker recognition system, can be a solution of additional difficulty like e.g. change of the mobile phone unit, SIM card or number by a caller.

This work presents an idea of the use of various relations between features for automatic recognition of cases in emergency telephone call systems.

The paper is organized as follows. After an introduction in this section, a model of the dependence analysis is presented in Section 2. Section 3 describes a method of determination of probabilities in the correlation matrices. Analysis of features correlation and experimental results are presented in Sections 4 and 5. The last section contains final remarks.

II. Dependence Analysis Model

The correlations defined above measure changes of parameters of one feature caused by changes of parameters of another feature or some features. In other words, such correlation describes relations between two or more parameters, not only distinct parameters. The simplest case is the relation between two parameters of one feature.

Let P_j be the matrix, which describe numerical dependences between all possible pairs of parameters for j-th feature. Rows of matrix P_j correspond to the parameters of j-th feature of the reference (just received) conversation. Columns correspond to the respective parameters of the same feature of the conversation, which is already stored in the database. The matrix P_j of size $N \times N$ for N possible parameters is defined as

$$P_j = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1N} \\ p_{21} & p_{22} & \cdots & p_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ p_{N1} & p_{N2} & \cdots & p_{NN} \end{bmatrix}. \qquad (2)$$

More advanced case is when we calculate correlations between two different features. The correlations between two features f_j and f_k are described by the matrix $P_j(f_k)$. Parameter of j-th feature of the reference conversation and respective parameter of the same feature of the conversation already stored in the database are influenced by changes of feature f_k.

Assume that feature f_k is the numerical value. The difference between numerical value of feature f_k of the reference conversation and respective parameter of the same feature of the conversation already stored in the database is denoted as d. Thus, the correlation matrix $P_j(f_k) = P_j(d)$ and is defined as

$$P_j(d) = \begin{bmatrix} p_{11}(d) & p_{12}(d) & \cdots & p_{1N}(d) \\ p_{21}(d) & p_{22}(d) & \cdots & p_{2N}(d) \\ \cdots & \cdots & \cdots & \cdots \\ p_{N1}(d) & p_{N2}(d) & \cdots & p_{NN}(d) \end{bmatrix}. \qquad (3)$$

The recognition process is based on a choice of an element of the matrix $P_j(d)$ which corresponds to chosen parameters of features.

III. Method of Determination of Probabilities in Correlation Matrices.

As an example of the correlation let us consider a problem of searching a caller suspicious for execution of two calls registered in two different cities. The feature f_j means the city and feature f_k is a time of registration of the call. Reference conversation and conversation already stored in the database are recorded in some time shift. We consider four illustrative cities in Wielkopolska Region (Poland) as presented in Fig. 1.

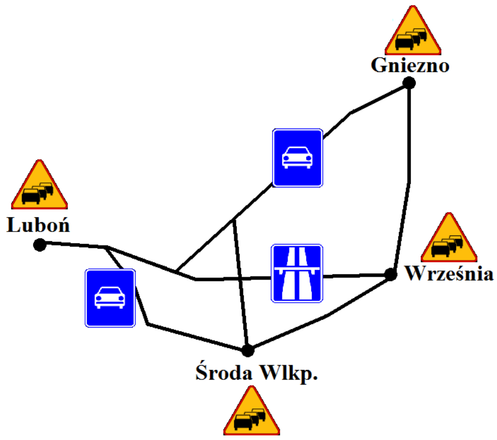

Figure 1. Location and road conditions of four illustrative cities in Wielkopolska Region

The distances between these cities for the road transport, according to the Google Maps (calculated on May 19th, 2015), are presented in Tab. 1. Departure cites are presented in columns, the destination cities are presented in rows. Small distances (up to one kilometer) between forward and backward travel directions are possibly caused by various arrangement of traffic lanes and road junctions. In that case the matrix is not symmetric.

TABLE I. Distances [in kilometers] between 4 illustrative cities in Wielkopolska Region

	Gniezno	Luboń	Środa Wlkp.	Września
Gniezno	0	59	48	26
Luboń	60	0	36	51
Środa Wlkp.	49	35	0	25
Września	25	51	26	0

Car travel time between these four cities, also according to the Google Maps data, are presented in Tab. 2. These values obviously depend on the road distances, but also on various obstacles, e.g. occurrence of traffic congestions, speed limits, and renovation works. The road conditions are not the same in both directions. Thus, this matrix is also not symmetric.

TABLE II. TIME DIFFERENCES [IN MINUTES] BETWEEN 4 ILLUSTRATIVE CITIES IN WIELKOPOLSKA REGION

	Gniezno	**Luboń**	**Środa Wlkp.**	**Września**
Gniezno	0	37	34	29
Luboń	41	0	35	37
Środa Wlkp.	37	31	0	26
Września	25	38	27	0

For two notifications from two different cities, relatively close to each other in time, we would like to determine a probability that both of them refer to the same person. The probability that two calls are executed by the same caller grows with the passage of time. For the mean travel time (*MTT*) and the time difference between the compared conversations denoted as d a probability p that two calls refer to the same person may be determined as follows

$$\begin{array}{l} \text{if } (MTT+50\%)<d \text{ then } p=1; \text{otherwise} \\ \text{if } (MTT+40\%)<d \text{ then } p=0.9; \text{otherwise} \\ \text{if } (MTT+30\%)<d \text{ then } p=0.8; \text{otherwise} \\ \text{if } (MTT+20\%)<d \text{ then } p=0.7; \text{otherwise} \\ \text{if } (MTT+10\%)<d \text{ then } p=0.6; \text{otherwise} \\ \text{if } MTT<d \text{ then } p=0.5; \text{otherwise} \\ \text{if } (MTT-10\%)<d \text{ then } p=0.4; \text{otherwise} \\ \text{if } (MTT-20\%)<d \text{ then } p=0.3; \text{otherwise} \\ \text{if } (MTT-30\%)<d \text{ then } p=0.2; \text{otherwise} \\ \text{if } (MTT-40\%)<d \text{ then } p=0.1; \\ \qquad \text{otherwise } p=0 \end{array} \tag{4}$$

The corresponding values of correlation matrix $P_j(d)$, for d equal to 30 minutes, are given in Tab. 3. Figure 2 illustrates the matrix using grayscale levels.

TABLE III. MATRIX $P_j(30)$ FOR COMPARISON BETWEEN 4 CHOSEN CITIES IN WIELKOPOLSKA REGION

	Gniezno	**Luboń**	**Środa Wlkp.**	**Września**
Gniezno	p_{11}=1	p_{12}=0.3	p_{13}=0.3	p_{14}=0.5
Luboń	p_{21}=0.2	p_{22}=1	p_{23}=0.3	p_{24}=0.3
Środa Wlkp.	p_{31}=0.3	p_{32}=0.4	p_{33}=1	p_{34}=0.6
Września	p_{41}=0.6	p_{42}=0.2	p_{43}=0.6	p_{44}=1

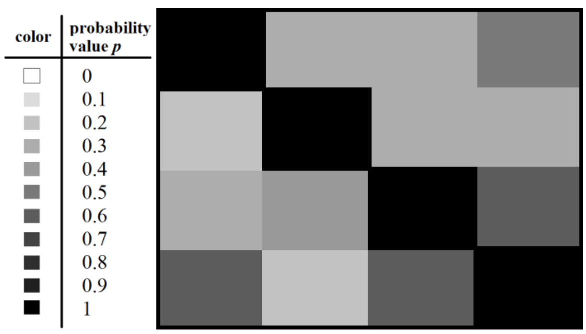

Figure 2. Image illustrating the correlation matrix

In described case, probability p is referred as a probability of true notification, so the features matching mechanism brings out these notifications, which are reliable. Therefore the records related to the cheaters have a relatively low impact on the resulting score or even are not taken into account at all.

On the other hand, if we want just to detect a cheater, it makes sense to determine the highest probability for the cases where two notifications cannot be reliably reported by the same person. The probability of the false notification p_{false} is defined by the formula:

$$p_{false}=1-p. \tag{5}$$

IV. ANALYSIS OF FEATURES CORRELATION

Correlations between features can be used in order to analyze the calls to the ENC. As example we consider the ENC in the Wielkopolska Region, Poland. For initialization of matrices, the probabilities of making of two calls by the same caller travelled between two cities corresponding to distances and time differences are calculated for 25 largest cities, according to the Google Maps data (Thursday, May 19, 2015).

We can notice that maximal value of time difference between cities increased by 50% does not exceed 326 minutes. This value is rounded up to 6 hours (360 minutes). For this time difference it is sure that speaker may move between any randomly chosen cities in Wielkopolska Region. It is the longest time for correlation analysis.

We arbitrary chose eight values of d parameter as ends of the ranges:

- d_1 = 10 minutes for the range 0–10 minutes
- d_2 = 30 minutes for the range 10–30 minutes
- d_3 = 60 minutes for the range 30–60 minutes
- d_4 = 90 minutes for the range 60–90 minutes
- d_5 = 120 minutes for the range 90–120 minutes
- d_6 = 180 minutes for the range 120–180 minutes
- d_7 = 240 minutes for the range 180–240 minutes
- d_8 = 360 minutes for the range 240–360 minutes.

Images illustrating correlation matrices with probabilities of making of two calls by the same caller travelled between two cities for d_1–d_8 values of time distance are presented in Fig. 3. a)–h) in the left column. The values of grayscale levels are the same as in Fig. 2.

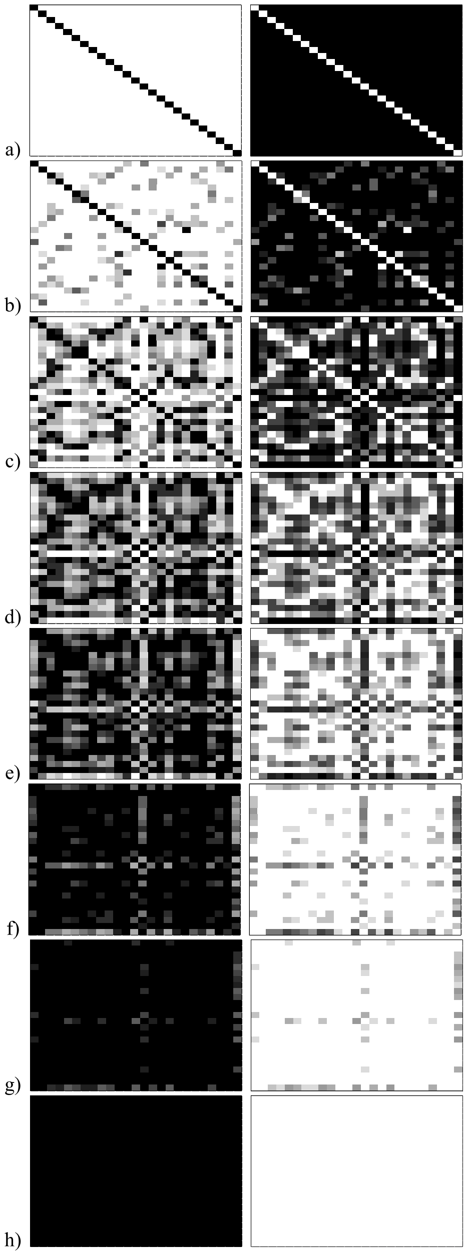

Figure 3. Images illustrating correlation matrices for: a) d_1 = 10 minutes, b) d_2 = 30 minutes, c) d_3 = 60 minutes, d) d_4 = 90 minutes, e) d_5 = 120 minutes, f) d_6 = 180 minutes, g) d_7 = 240 minutes, and h) d_8 = 360 minutes for probabilities of true (on left) and false notification (on right)

For a relatively short time difference it is impossible to move between any city and the correlation matrix is the identity matrix (Fig. 3a). In 30 minutes the probabilities of travel which are greater than zero are just for the nearest cities (Fig. 3b – some non diagonal matrix entries occur). With the growing time difference the probabilities increase and the number of non zero matrix entries also increases. With a further passage of time, the contrast of the whole illustrative images decreases. For the time difference equal to 240 minutes, there is a large number of matrix entries close to 1, which correspond to black image regions. For the last range, it is possible to move between any of the cities, even in road conditions which extend the time of travel by 50%. All probabilities are equal to 1, what is illustrated as black image (Fig. 3h).

The similar analysis may be conducted for the probability of the false notification and is presented in Fig. 3. a)–h) in the right column. With the growing time difference the probabilities that the speaker cheats decrease and the number of zero matrix entries increases.

V. Experimental results

To check the proposed method in practice we prepared an experimental database, which consists of 251 emergency telephone conversations. Due to legal regulations there was not possible to use real emergency telephone records. Therefore telephone conversations were prepared by the authors, staff, and students of Poznan University of Technology.

The aim of the experiments was to determine the percentage of matching between two notification records: the current one (the reference record) and the record stored earlier in the database. The recognition system was adjusted exclusively for the caller recognition. In tests all features were taken into account, but the analysis was focused on changes of the caller's locations. We choose two notifications from the same caller corresponding to two different cities. According to Table II, in the first conversation the caller reported an event happened in Luboń. The second registered event happened in Września.

The proposed method was tested with two scenarios: case impossible and case possible. In both cases we consider a simplified search without taking correlations into account and the advanced search with correlations. Moreover, we consider two analysis modes: the analysis for confirmation of the truth and the analysis for confirmation of the untruth (cheating).

As the first scenario, we choose the time shift between two notifications and the respective events equal to 6 minutes. In fact, it was impossible (i.e., with probability equal to 0) to travel by car from Luboń to Września in 6 minutes because the *MTT* for these cities is equal to 38 minutes (cf. Tab. II) and this reduced by 40%, according to formula (4), is still greater than 6 minutes.

Performing the analysis for confirmation of the truth with the simplified matching mechanism, the same caller was recognized with 99.3% of matching. This result means that it is very probably that the same person reported these two events but it is false because, as it was clarified above, in reality it is impossible.

Therefore we should use correlations for decrease an influence of possible false notification on matching the results. For 25%, 50%, and 75% of correlation share in all the weights (compare (1)) the matching result is 74.5%, 49.7%, and 24.8%, respectively. It means that even if it was the same caller and these events may happened, the caller most probably could not see them. Consequently, some reported facts are false, the notification is unreliable and the final matching score is decreased.

In the second analysis mode, we would like to find and expose the person who was a cheater. We use probabilities for false notification (5) as complementary to probabilities of true notification. For 25%, 50%, and 75% of correlation share in all the weights the matching result is 99.5%, 99.7%, and 99.8%. The probability is very high and it means that the same speaker was registered in two conversations and he or she possibly cheated. The experimental results are collected in Tab. IV.

TABLE IV. EXPERIMENTAL RESULTS FOR CALLER RECOGNITION (CASE IMPOSSIBLE)

Correlation weight	**Sum of weights for other features**	**Percentage of correlation weight**	**Matching result**	
			true notification	**false notification**
0	144	0%	99.3%	
48		25%	74.5%	99.5%
144		50%	49.7%	99.7%
432		75%	24.8%	99.8%

As the second scenario, we choose, as in the previous one, two notifications from the same caller corresponding to two different cities (Luboń and Września), but the time shift between these notifications and events is much longer and equals 65 minutes. In this case it was possible (with probability equal to 1) to move between these cities (the *MTT* is equal to 38 minutes (cf. Tab. II) and this even increased by 50%, according to formula (4), is still smaller than 65 minutes).

Using this scenario and the first analysis mode (confirmation of truth) with the simplified matching mechanism, the same caller was recognized with 98.6% of matching, which again means that it is very probably that the same person reported these two events, but this time it is in fact true.

Using the correlations for decrease influence of a possible false notification on the matching results for 25%, 50%, and 75% of share in all the weights (cf. (1)) the matching result is 99.0%, 99.3%, and 99.7%, respectively. This means that it was the same caller and event may happened, he or she most probably could see that event, the reported facts are true and the notification is reliable. Thus finally, the matching score is plausibly increased.

If we would like to find and expose a person who was a cheater, we use probabilities for the untruth notification (5), which are complementary to probabilities of the truth notification. For 25%, 50%, and 75% of share in all the weights the matching result is 74.0%, 49.3%, and 24.7%, respectively. These probabilities are smaller than before. This means that the same speaker was registered in two conversations and he or she possibly did not cheat. The experimental results are collected in Table V.

TABLE V. EXPERIMENTAL RESULTS FOR CALLER RECOGNITION (CASE POSSIBLE)

Correlation weight	**Sum of weights for other features**	**Percentage of correlation weight**	**Matching result**	
			true notification	**false notification**
0	144	0%	98.6%	
48		25%	99.0%	74.0%
144		50%	99.3%	49.3%
432		75%	99.7%	24.7%

VI. CONCLUDING REMARKS

The correlation based procedure is an integral part of the authors' advanced database search mechanism. It takes dependences between features into consideration. The calculated probabilities affect the results of recognition. Depending on the analysis mode it can decrease or increase the value of matching for the cheater. In case of the caller recognition, a small value of the correlation matrix entry, which determines that two calls refer to the same person with a low probability, decreases the importance of this particular caller and moves this caller backwards on the list of results. The results of experiments show that efficiency of the proposed recognition system is very high.

In the target recognition system the entire correlation matrices may not to be stored in the database memory. Values may be calculated automatically using actual environmental conditions.

In future, the authors plan to expand the database records and to perform further experiments on recognition of notifications.

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