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INFORMATION FLOW RECOGNITION IN RADIO COMMUNICATION CHANNEL BETWEEN AIR TRAFFIC DISPATCHER AND AIRCRAFT CREW

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Abstract. *Classification of data streams according to phases of flight (maneuvering, takeoff, flight, descending, entrance to the landing area, landing, maneuvering) is proposed. Development of algorithm, which uses a dictionary and grammar to refine the recognition results, is given.*

Keywords: flight safety; radio communication channel; Markov chain; commands grammar; speech recognition; phases of flight; air traffic controller; crew.

Introduction

Statistical analysis strongly suggests that a significant part of aircraft accidents caused due to crew and flight operator errors at the time of voice messages hearing and processing [1], [4]. Obviously, information perception mistakes and raised emotional state are the main reasons for making such false-fatal decisions [2], [3].

This paper introduces classification of data streams according to phases of flight (maneuvering, takeoff, flight, descending, entrance to the landing area, landing, maneuvering after landing). It proposes to use separate vocabulary and grammar commands sets for each of the data streams, according to flight stage. Also the development of algorithm which uses a dictionary and grammar to refine the recognition results is given [5]. Offered classification and algorithm can together significantly improve efficiency of the commands recognition problem solving in radio communication channels between the dispatcher and the crew of the aircraft.

Determination of information flow

Information flow is a time sequence of information units generated by source and received with some medium to the receiver, changing its state. In case of this paper, radio channel of communication between flight operator and crew can be used as a medium which information streams is transmitted through.

Classification of information flow in the channel sharing «Dispatcher-crew»

According to the conventional classification of flight stages, information flows are structured as follows:

1. Preparing for flight, maneuvering and run.
2. Takeoff and climb.
3. Flight route and preparation to reduce.
4. Reduction, the implementation scheme of standard arrival and entrance to the takeoff and landing area.
5. Entering to the landing line and then landing
6. Maneuvering in the area of disembarkation.

Information flow consists of information units (subject alphabet), connected by grammar rules (structure of messages). Each flight stage characterized by its own alphabet and grammar (Fig. 1).

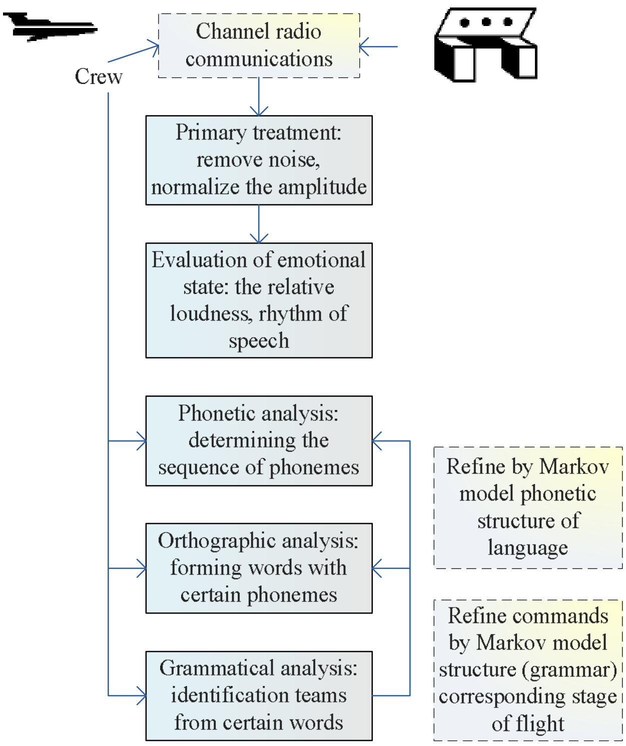

Fig. 1. The general scheme of information flow detection in air navigation systems

Mathematical model of information flow

Let $\Phi_1,\ldots,\Phi_m$ is set (alphabet, vocabulary) of information units. Sequence of these units makes a message (word, sentence) (Fig. 2).

In communication channels "Flight operator-crew" sequence of information units can be considered as a series (1)

$$x(t_i)=\sum_{k=1}^{m}\Phi_k \mathrm{I}(k,l(t_i)),\ i=1,\ \ldots,\ n, \quad (1)$$

where $\mathrm{I}(k,l(t_i))=\begin{cases}1, & k=l(t_i),\\ 0, & k\neq l(t_i)\end{cases}$ is indicator function; $l(t_i)$ is controlling Markov chain with a discrete set of values $\{1\ldots m\}$, structure is defined by a grammar information flow. According to the definition of the model, $l(t_i)$ can change its state at a different time moments.

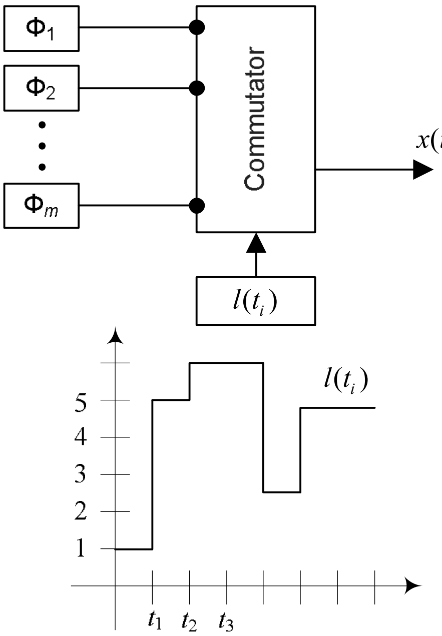

Fig. 2. Scheme of the formation of information flow control using Markov chain $l(t_i)$

The model of information flow $O_k(t_i)$, $k=1, \ldots, Q$; $i=1, \ldots, N$, which grammar describes by the Markov chain $l_k(t_i)$, defined by a matrix of transition probabilities

$$\Pi_k=\begin{pmatrix}\pi^k{}_{11},\pi^k{}_{12},\ldots\ldots,\pi^k{}_{1m}\\ \pi^k{}_{21},\pi^k{}_{22},\ldots\ldots,\pi^k{}_{2m}\\ \ldots\\ \pi^k{}_{M1},\pi^k{}_{M2},\ldots\ldots,\pi^k{}_{mm}\end{pmatrix}. \quad (2)$$

The value of transition probabilities (matrix elements Π_k) are determined by the type of information flow O_k and its grammar.

Example. Development of phonetic structure with Russian language, as one of the ICAO languages

Let the voice messages transmitted online. In order to analyze proposed model, the software that allows phonological analysis of speech communications was built. According to the classical definition, phonemes – is a smallest units of sound that make up the meaningful units of language (words and morphemes). In the case of model (1) for the speech signal, we assume the concept of phonemes and basic sound constituent equivalent. Phonological system of the modern Russian language has vowels - “а”, “о”, “у”, “э”, “ы”, “и”, hard “б”, “в”, “г”, “д”, “ж”, “з”, “й”, “к”, “л”, “м”, “н”, “п”, “р”, “с”, “т”, “ф”, “х”, “ц”, “ч”, “ш” and softened “бь”, “вь”, “гь”, “кь”, “ль”, “мь”, “нь”, “пь”, “рь”, “сь”, “ть”, “фь”, “хь”, “чь”, “щ” consonants. Resulting set of phonemes was taken as the set of states of Markov chain control. Also developed software for the automated processing of data in electronic form allows to estimate conditional probabilities of transitions between phonemes. As a control sample was taken into a technical field of air navigation in total volume of 200 pages. A fragment of the resulting matrix of conditional probabilities estimations of transitions between phonemes are shown in Table. 1.

Table 1

Fragment of conditional probabilities table of transitions between Russian phonemes

	а	о	у	э	ы	и	й	б	бь	в	вь
а	0,007	0,024	0,008	0,005	0,000	0,024	0,071	0,017	0,003	0,055	0,011
о	0,002	0,021	0,006	0,003	0,000	0,020	0,082	0,038	0,008	0,085	0,018
у	0,010	0,021	0,006	0,005	0,000	0,033	0,056	0,028	0,017	0,044	0,013
э	0,002	0,020	0,007	0,004	0,000	0,018	0,074	0,015	0,015	0,033	0,008
ы	0,004	0,013	0,004	0,003	0,000	0,022	0,130	0,028	0,003	0,085	0,006
и	0,005	0,036	0,010	0,004	0,000	0,032	0,110	0,019	0,004	0,070	0,008
й	0,193	0,014	0,098	0,477	0,000	0,014	0,005	0,007	0,002	0,013	0,002
б	0,097	0,193	0,097	0,003	0,327	0,003	0,010	0,001	0,000	0,001	0,005
бь	0,142	0,000	0,003	0,620	0,225	0,000	0,010	0,000	0,000	0,000	0,000
в	0,180	0,243	0,028	0,009	0,083	0,008	0,006	0,005	0,002	0,009	0,003
вь	0,021	0,001	0,000	0,569	0,390	0,001	0,010	0,000	0,000	0,001	0,000
г	0,058	0,582	0,042	0,001	0,000	0,004	0,003	0,002	0,000	0,006	0,001
гь	0,000	0,000	0,000	0,355	0,645	0,000	0,000	0,000	0,000	0,000	0,000
д	0,232	0,208	0,095	0,001	0,035	0,004	0,012	0,002	0,002	0,023	0,029
дь	0,060	0,003	0,011	0,567	0,311	0,004	0,006	0,006	0,000	0,003	0,000
ж	0,147	0,007	0,021	0,421	0,147	0,003	0,004	0,006	0,002	0,002	0,001

Fig. 3 shows a two-dimensional graph, histogram distribution of transitions between phonemes. This information provides an opportunity to significantly reduce the number of viewing options to solve the phonemes identifying problem.

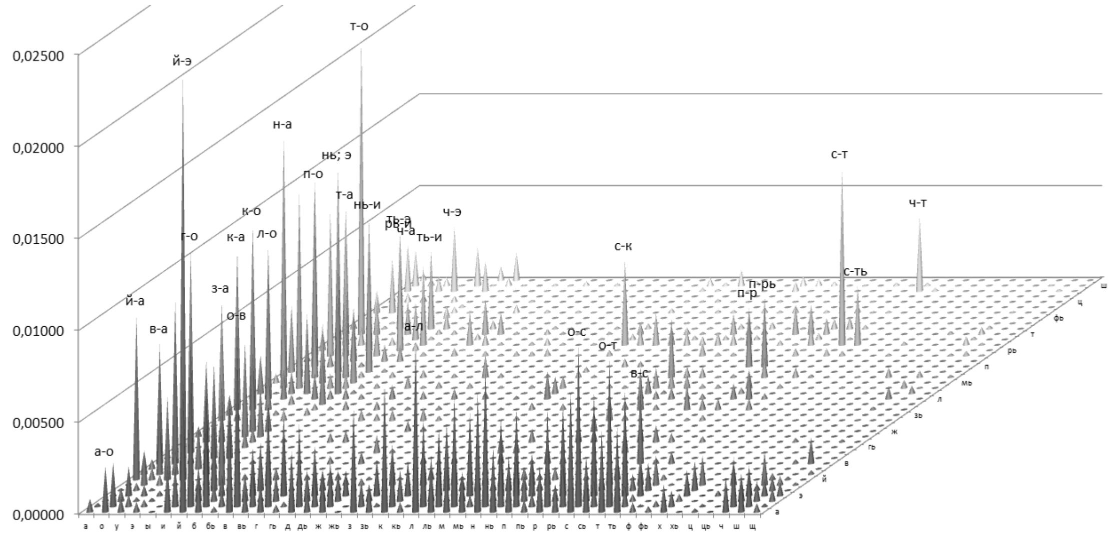

Fig. 3. 3D graph with estimation of distribution of conditional probabilities of transition between Russian phonemes. Figure signed most common combination «й-э», «т-о», «н-а» and others

Algorithm of information flow recognition

Let for the k th flow of information was obtained the resulting matrix of transition probabilities $\mathbf{\Pi}_k$ (2). Digitized radio channel communications signal S is segmented [1] and applied to the receiver input H with a sequence $W = (w_1,\ ...,\ w_n,\ w_{n+1},\ ...)$ parts of audio stream.

The receiver H is characterized by matrix $\mathbf{Q}^H$ of recognition probability:

$$Q^H = \begin{bmatrix} \pi_{11} & \dots & \pi_{1m} \\ \dots & \dots & \dots \\ \pi_{m1} & \dots & \pi_{mm} \end{bmatrix}, \qquad (3)$$

where m is number of phonemes in dictionary.

Matrix $\mathbf{Q}^H$ obtained through research and provides information with detection probability of receiver H for each dictionary phoneme in relation to other phonemes that were fed to the input of the receiver as fragments of training samples. For example, the first row of the matrix $\mathbf{Q}^H$ provides information about probability distribution of each phoneme recognition if receiver inputs fragment of the phoneme «а».

Let on the previous step of the algorithm was obtained the vector $P^*_{i-1}(w_{i-1})$, of probability distribution of phonemes for $i-1$ fragment of audio stream S.

The next step of the algorithm, using vector $P^*_{i-1}(w_{i-1})$ and known matrix $\mathbf{\Pi}_k$ the extrapolated (estimated) vector of phonemes probabilities in the $i+1$ step is obtained:

$$P_i^{ext}(w_i) = P^*_{i-1}(w_{i-1}) \times \mathbf{\Pi}_k. \qquad (4)$$

Let the next i-th part of audio stream S is transmitted to receiver input H. Receiver H, according to their characteristics Q^H (3), generates the appropriate phonemes distribution probability vector:

$$P_i(w_i) = (p_{1i}, ..., p_{mi}),\ \ \sum\nolimits_{j=1}^{m} p_{ji} = 1. \qquad (5)$$

Using the obtained vectors $P_i(w_i)$ and $P^{\text{ext}}(w_i)$, the resulting probability distribution vector for the i th segment is calculated:

$$P_i^*(w_i) = (p_{i1}^*, ..., p_{im}^*);$$
$$p_{ik}^* = \frac{P_{ik}^{\text{ext}} P_{ik}}{\sum\nolimits_{j=1}^{m} P_{ij}^{\text{ext}} P_{ij}},\ k = \overline{1,m}. \qquad (6)$$

It should be noted that for the first segment $P_1^*(w_1) = P_1(w_1)$, because there is no previous fragment for him.

Thus, the resulting vector $P_1^*(w_1)$ contains refined information based on characteristics of receiver H and transitions matrix $\mathbf{\Pi}_k$ on i th segment of realization. The most probable phoneme in this segment should be considered phoneme, which corresponds to the largest value vector $P_i^*(w_i)$:

$$F_i = \arg\max{}_j\, P_i^*(w_i). \qquad (7)$$

The algorithm should be applied for all fragments $i+1,\ i+2,\ ...$ Resulting sequence $F = (F_1,\ ...,F_{i-1},\ F_i,\ F_{i+1},\ ...)$ should be considered as the most likely result based on characteristics of receiver H and transitions matrix $\prod_k$ (Fig. 4).

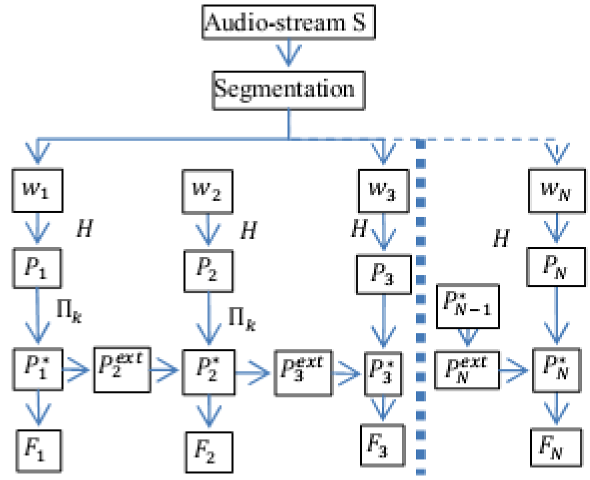

Fig. 4. Recognition algorithm of audio stream using receiver characteristics and the matrix of transitions between phonemes

An example of application of the proposed model

During a real flight, quality of audio messages can significantly deteriorate due to significant interference and channel distortion in radio communications. In such situations, the transition matrix $\mathbf{\Pi}_k$ (2) can significantly improve the recognition accuracy of audio information. For example, let the dictionary system consists of the following patterns of phonemes Russian language – «а», «о», «в», «г», «т», «ф», «х», «ц». Empirically determined probability matrix recognition of phonemes using correlation matching with templates on Table 2.

Table 2

Example matrix Q^H (3) with recognition probabilities of 6 phonemes of Russian («а», «о», «в», «г», «т», «ф», «х», «ц»), obtained empirically. First row of the matrix shows that the phoneme “a” in 60 % of cases detected correctly in 40 % of cases recognized as phoneme “o”

	«а»	«о»	«в»	«г»	«т»	«ф»	«х»	«ц»
«а»	0,6	0,4	0	0	0	0	0	0
«о»	0,4	0,6	0	0	0	0	0	0
«в»	0	0	0,6	0,4	0	0	0	0
«г»	0	0	0,4	0,6	0	0	0	0
«т»	0	0	0	0	0,6	0,4	0	0
«ф»	0	0	0	0	0,4	0,6	0	0
«х»	0	0	0	0	0	0	0,6	0,4
«ц»	0	0	0	0	0	0	0,4	0,6

Let on the first stage were received following phonemes (the degree of compliance with the standard phonemes is calculated by selecting a template according to the maximum value of the correlation coefficient between the obtained sample and a reference sample of phonemes and use the vector of probabilities of the corresponding row of the matrix Table 2):

1 phoneme	2 phoneme	3 phoneme	4 phoneme	5 phoneme
«г» - 0.6	**«о» - 0.4**	**«т» - 0.4**	**«о» - 0.4**	**«в» - 0.3**
«х» - 0.4	**«а» - 0.6**	**«ц» - 0.6**	**«а» - 0.6**	**«ф» - 0.7**

To apply algorithm on Fig. 3, it is necessary to use normalized data in Table 1:

	а	о	в	г	т	ф	х	ц
а	0	0,14952	0,3468	0,10765	0,26315	0,0311	0,08971	0,01196
о	0,0081	0	0,39119	0,22819	0,32599	0,00489	0,03545	0,00611
в	0,39322	0,53236	0	0,02419	0,04053	0,00060	0,00605	0,00302
г	0,08986	0,89869	0,00898	0	0,00245	0	0	0
т	0,27124	0,63821	0,07578	0,00518	0	0,00079	0,00199	0,00678
ф	0,5937	0,25	0,0625	0,0312	0,0625	0	0	0
х	0,24896	0,6016	0,08921	0,03319	0,02074	0,00414	0	0,00207
ц	0,53676	0,34558	0,08823	0,00735	0,02205	0	0	0

On the first step of algorithm resulting vector $P_1^*(w_1)$ coincides with the vector that returns the receiver H:

	а	о	в	г	т	ф	х	ц	**Result**
$P_1^*(w_1)$	0	0	0	0,6	0	0	0,4	0	**«Г»**

According to expression (4), the vector $P_2^{ext}(w_2) = P_1^*(w_1) \times \mathbf{\Pi}_k$:

	а	о	в	г	т	ф	х	ц
$P_2^{ext}(w_2)$	0,15350	0,7798	0,04107	0,01327	0,00976	0,0016	0	0,0008

After mapping by expression (6) vector $P_2^{ext}(w_2)$ та $P_2(w_2)$, obtain a vector $P_2^*(w_2)$:

	а	о	в	г	т	ф	х	ц	**Result**
$P_2^*(w_2)$	0,22795	0,77205	0	0	0	0	0	0	**«О»**

Similarly, following probability vectors are obtained:

	а	о	в	г	т	ф	х	ц	**Result**
$P_3^{ext}(w_3)$	0,0062	0,0340	0,3810	0,2007	0,3116	0,0108	0,0478	0,0074	
$P_3^*(w_3)$	0	0		0	0,9654	0	0	0,0345	**«Т»**
$P_4^{ext}(w_4)$	0,2804	0,6280	0,0762	0,0052	0,0007	0,0007	0,0019	0,0065	
$P_4^*(w_4)$	0,4010	0,5989	0	0	0	0	0	0	**«О»**
$P_5^{ext}(w_5)$	0,0048	0,0599	0,3734	0,1798	0,3007	0,0154	0,0572	0,0084	
$P_5^*(w_5)$	0	0	0,9122	0	0	0,0877	0	0	**«В»**

Thus, as a result of the above algorithm is a sequence of «Г-А-Ц-А-Ф» on the receiver output was updated to a sequence «Г-О-Т-О-В», which is consistent with the current word of Russian.

Conclusions. This example shows that the matrix of conditional probabilities of transitions between phonemes can significantly improve the recognition of phonemes. It should also be noted that this statistical approach can be used in subsequent stages of recognition – Spelling and grammatical (Fig. 1). This level of analysis is necessary to use orthographic matrix of conditional probabilities of transitions between syllables and grammatical level – matrix transition probabilities between words corresponding language.

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К. І. Прокопенко. Розпізнавання інформаційних потоків в каналі радіо-обміну між диспетчером та екіпажем повітряного судна

Проведено класифікацію інформаційних потоків в каналі обміну «диспетчер-екіпаж» у відповідності до фаз польоту (маневрування, зліт та набір висоти, політ, зниження, вхід до зони приземлення, приземлення). Розроблено алгоритм розпізнавання, який використовує словник та граматику команд для підвищення якості розпізнавання інформаційних потоків.

Ключові слова: безпека польоту; канал радіозв'язку; ланцюги Маркова; граматика команд; розпізнавання мови; фази польоту; авіадиспетчер; екіпаж.

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Прокопенко Константин Игоревич. Распознавание информационных потоков в канале радиообмена между диспетчером и экипажем воздушного судна

Проведена классификация информационных потоков в канале обмена «диспетчер-экипаж) в соответствии с фазами полета (маневрирование, взлет и набор высоты, полет, снижение, вход в зону посадки, посадка). Разработан алгоритм распознавания, который использует словарь и грамматику команд для повышения качества распознавания информационных потоков.

Ключевые слова: безопасность полета; канал радиосвязи; цепи Маркова; грамматика команд; распознавание речи; фазы полета; диспетчер; экипаж.

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