The use of mobile phones to monitor the status of patients with Parkinson's disease*

Yulia A. Shichkina[1]†, Galina V. Kataeva[2], Yulia A. Irishina[2], and Elizaveta S. Stanevich[1]
[1]*St. Petersburg State Electrotechnical University "LETI"*
St. Petersburg, Russia
[2]*N.P.Bechtereva Institute of the Human Brain of the Russian Academy of Sciences*
St. Petersburg, Russia

Received: February 20, 2020; Accepted: June 2, 2020; Published: June 30, 2020

Abstract

The article presents the results of research on the problem of using the capabilities of Mobile Touch Phones on the Android Platform for monitoring the status of patients with Parkinson's disease. The purpose of the study is to create a system for user authentication to exclude the collection of incorrect data and data not related to the patient, and for classifying the patient's state to automate the monitoring process of his state. The article describes the software and hardware architecture of the solution, which includes mobile phone modules, a system for sending data to a server, and separate modules for doctors. An apparatus of fuzzy logic was used to send data to the server; neural networks are used to process the data in the task of classifying the state of patients. Data is collected from the phone in two modes: interactive and background. In the interactive mode, the patients during the day can mark the level of their activity, the presence of dyskinesia, their medications taking and other data that cannot be collected without the participation of the patient himself. In the background monitoring, data are collected from mobile phone sensors. Further, the knowledge that will be extracted from this data using data mining techniques will minimize the interactive part of the monitoring. This will make the monitoring process easy for patients and informative for neurologists.

Keywords: Parkinson's disease, smartphone, motion sensor, patient status monitor

1 Introduction

Parkinson's disease (PD) is a chronic, progressive brain disease primarily associated with the degeneration of the dopaminergic neurons of the substantia nigra. Symptoms of PD are movement disorders (hypokinesia combined with rigidity, resting tremor and postural instability), as well as a wide range of non-motor manifestations (vegetative, sensory, mental, etc.) [2].

The social significance of PD is the prevalence of the disease: there are about 10 million patients in the world, PD is the second disease among neurodegenerative diseases after Alzheimer's disease in prevalence [3]. In Russia, there are about 210 thousand patients with PD, 3/4 of whom, according to the results of medical and social expertise, have some degree of disability [4]. With age, the frequency of

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 11(2):55-73, June 2020
DOI:*10.22667/JOWUA.2020.06.30.055*

*This paper is an extended version of the paper that appeared in the proceedings of the 13th International Symposium on Intelligent Distributed Computing (IDC 2019) [1]. The article is supplemented by a description of the process of sending data to a server using a fuzzy logic apparatus, a description of the data exchange scheme between the server and mobile phones, information about neural networks and used databases, and a change in Architecture of the information system for monitoring the status in patients with PD.

†Corresponding author: Faculty of Computer Science and Technology, St. Petersburg State Electrotechnical University "LETI", ul. Professora Popova 5, 197376 St. Petersburg, Russian Federation, strange.y@mail.ru, Tel: 89819636645

PD increases from 1% in the age group of 60–80 years to 4–5% in the group older than 80 years [3]. Unfortunately, there is still no pathogenetic therapy that can prevent the progression of the disease, but the introduction more than 50 years ago into clinical practice of levodopa therapy was a revolutionary step in the therapy of this serious disease. Today, levodopa medications are the "gold standard" for the treatment of Parkinson's disease, allowing for many years to maintain the patient's physical activity. Also other dopaminergic medications can be used - as monotherapy in the debut of the disease, and as part of combination therapy in the different stages of the disease.

It is known that in Parkinson's disease, levodopa retain its effectiveness throughout the entire illness, but over time the action becomes not uniform, as in the first years of treatment, but intermittent, that is, so-called fluctuations appear. And these fluctuations can be not only motor, when hypokinesia (slowness), rigidity (stiffness), tremor (trembling), postural instability (imbalance when changing the position of the body in space) increase outside the action period of levodopa, but also many non-motor symptoms, such as for example, high blood pressure, palpitations, anxiety, pain in the limbs, urge to urinate, and many others. The manifestation of fluctuations can be from small - according to the type of "reducing the effect of a single dose" before the next intake of levodopa, to pronounced fluctuations of the "on-off" type. In patients with a disease duration of 10 years, the prevalence of fluctuations reaches 75-85%.

A change in the reaction to levodopa is also manifested in the development of dyskinesias, i.e. various violent movements both in the phase of the action of levodopa ("switching on") and in the period outside the action of levodopa ("switching off"). After 5-7 years of therapy with levodopa dyskinesia detected in 50-80% of patients [2].

Correction of fluctuations and dyskinesias primarily requires a good understanding of the dynamics of motor and non-motor manifestations of PD during the day, their connection with the use of levodopa and the phases of its action [2]. To do this, neurologists suggest patients to make special diaries, filling them every 30-60 minutes of wakefulness, where they note the time of taking the drugs, primarily levodopa, the degree of movement disorders and the presence of dyskinesia.

Self-observation diaries are important for a neurologist to evaluate the effects of levodopa and other medications, which may be different during the day (for example, there may be delayed "inclusions" or omissions of "inclusions"). In addition, it is important to assess patient compliance, i.e. the degree of consistency between the recommendations of the doctor and the patient taking the drugs. The fact is that the disease has neurodegenerative, and, therefore, progressive nature and the scheme of therapy is becoming more and more complex. Later in the treatment of the disease is the use of combination therapy with drugs from different groups. One patient in the developed stage applies up to 5 or more drugs in 4-6, and sometimes up to 8 doses per day. Monitoring the implementation of the dosing schedule is important both for the patient himself and for the neurologist.

Thus, monitoring the patient's condition and compliance is key to the success of correcting the main clinical manifestations of PD, including the almost inevitable modification of the clinical characteristics of a disease with prolonged dopaminergic therapy.

There are 5 stages of Parkinson's disease [5]. This classification was developed in the 1960s and is still in use today. Parkinson's disease is incurable. But, if patients do not use therapy, then the transition from the first stage to the fifth will be quick, as shown in Fig. 1 on the left. If the doctor applies the correct treatment scheme, it is possible not only to extend the current stage of the disease, so to speak, stop the progression of the disease, but also take a step to the previous stage, take a step to improvement. This picture of the development of the disease is schematically shown in Fig. 1 on the right.

At the same time, monitoring the patient state is associated with a number of difficulties:

- the impossibility of daily observation by a doctor in outpatient practice;
- the impossibility of analyzing the patient's diaries by the doctor for more than a few days preceding the date of the patient's visit;

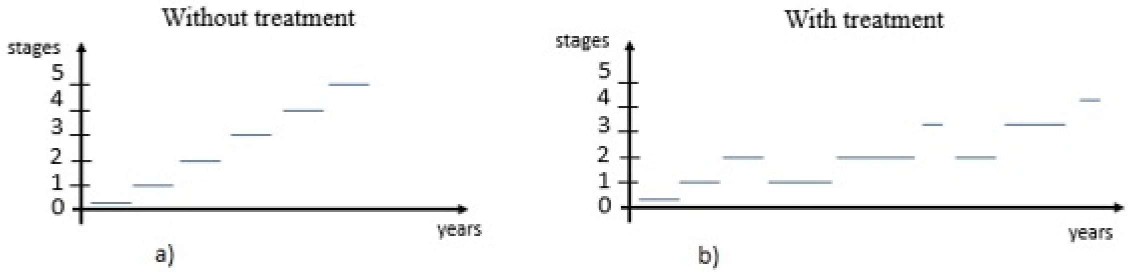

Figure 1: Parkinson's disease with and without treatment

- the impossibility of a general analysis of all pages of diaries for the entire period of observation of the patient;
- inaccuracy of filling the diary of patients for various reasons, including:
  - biased perception by the patient of his condition;
  - late filling diary;
  - difficulty filling diary;
  - loss of the diary, etc.

The use of mobile phone capabilities can help reduce these monitoring problems. Practical medicine and medical services supported by mobile devices so called mHealth solutions are nowadays rapidly developing and expanding field [6].

Since a mobile phone is a personal device that is almost always near the user, it would be logical to collect data that can help doctors diagnose the improvement or deterioration of patient's condition. With its help, the patient can record his state, take notes for the doctor, etc. In addition, part of the work of collecting data and its processing can be shifted from the shoulders of the patient and the doctor to mobile devices. A mobile phone can contain up to 14 different sensors [7], which allow tracking the change of coordinates, atmospheric pressure, air temperature, etc.

This article describes the architecture of the solution for monitoring the status of patients with PD using mobile devices and individual modules of the information system, such as data collection modules on a mobile phone, a module for sending data to a doctor's computer, and a module for automatically creating a diary. In addition to these modules, the article describes mathematical methods used to select the moment of sending data from the phone to the server and methods for optimizing database queries.

The article is structured as follows: the introduction presents the relevance of the development of methods for diagnosing and monitoring Parkinson's disease using modern information tools and technologies; section 2 provides an overview of existing solutions for monitoring PD symptoms using mobile devices; section 3 describes the conceptual model of the proposed solution; section 4 describes the user interfaces; in conclusion there are results of studies and briefly annotated further steps to develop an information system for monitoring the condition of patients with PD.

2 Review of existing solutions

As noted above, the mobile device market is rapidly developing, and now almost every person has a smartphone that can constantly process data from its sensors.

Today, more than 100000 mobile applications related to medicine are available [8]. They are used for various medical tasks, such as assessment of symptoms, assistance in patient navigation, locating patients, searching for medications, and tracking the treatment process [9, 10]. To improve cognitive functions in older people, it is possible to use games on a mobile device. The article [11] described how the created mobile application was used for cognitive stimulation in older people. The application offers a number of games for working with various cognitive functions (memory, concentration, etc.). Application testing was conducted on fifteen older people over a period of six months. Indicators of cognitive function in the sixth month of the study was significantly higher than at the end of the first month.

An application for patients with PD called "9zest Parkinson's Therapy & Exercises" has over 10000 downloads and is available on Google Play. This application contains a number of training and is intended to improve the condition of the person with PD. The application offers a combination of physical therapy, speech therapy and yoga to reduce the symptoms of PD, using the principles of neuroplasticity. For each new user, the application offers to initially pass a small test. Further, based on the results of this test, the application offers an individual training program. Exercises are developed by certified therapists and help in daily life to perform activities such as eating, writing text, dressing, walking, etc.

Since PD is a fairly common disease, it would be logical to assume that people who are somehow connected with it have something to share with each other. Nowadays there are enough social networks to gather communities and share online experiences. However, for these purposes, there is a special social network developed by MyHealthTeams. The social network provides access through the application "Parkinson's Support," which is available for download on Google Play. According to the developers, the application is mainly intended for friends and relatives of those people who suffer from PD. Users of the application can use it to find the necessary information for themselves, ask a question, get advice from those who already have experience and knowledge of PD.

The application "Monitoring of motion in Parkinson's disease, handshake control" has more than 1000 downloads on Google Play, and is a personal device that records and evaluates hand tremor. Applications allows to record parameters such as the frequency of occurrence of tremor, amplitude of tremor, the degree of change of tremor. All indicators are stored locally in the database, which allows to view the results of previous tests and compare the results. Test results are displayed both as a graph and as a diagram.

The application "HOOP Lite" is intended for the rehabilitation of patients with PD. It is a set of exercises that are complemented by rhythmic auditory stimulation. The application has few downloads from 100 to 500, which indicates that this approach is not popular. On the other hand, a small number of downloads may be due to the small number of exercises offered by the application.

For the diagnosis of PD, there is also the so-called finger-tapping test, or the "Finger-tapping test". Since this test is designed to assess the fine motility of the fingers, it is used in everyday clinical practice to evaluate hypokinesia, the main symptom of PD [12]. This also allows to do another application "CNS - Finger Tapping Test", which has more than 1000 downloads.

All the above applications are available for download on Google Play. Next will be considered applications that are described in scientific publications.

The article [13] describes an application that allows you to determine the severity of PD symptoms by a user-drawn helix. The user is shown on the screen a spiral that he needs to repeat. From the deviations of the drawn line from the original, the application determines the presence and severity of hypokinesia and tremor, the characteristic manifestations of PD syndrome. The following test indicators are taken into account: average test passing time, average radial deviation, maximum radial deviation, intersection frequency (the number of times the deviation changed the sign divided by the total number of control points [13]) and others. To analyze the test performance, the application uses data from the phone's screen sensor, namely the X and Y coordinates and the pressure force on the screen.

The Android platform has an accelerometer in its arsenal. In [14], this sensor is used to identify and measure tremor in patients. The paper says that to correctly measure the severity of tremor of the hands, it is necessary to fix the smartphone on the user's hand and repeat the experiment at least 10 times. Data is stored in the device's memory and can be downloaded in text form for further analysis. It should be noted that this work is not the only one where the tremor measured using a smartphone.

Another application "HopkinsPD" [15] has several possibilities for assessing the symptoms of PD: voice, finger tapping, gait, postural instability and reaction time. The voice test prompts the user to pronounce the specified combination of sounds for as long as he can. This test is designed to detect disorders such as dysphonia. The next symptom that this application can track is postural instability (a clinical syndrome, meaning a violation of the ability to equalize equilibrium with a change in body position in space). To diagnose this symptom, the application offers the user to stand straight without help for 30 seconds. The following test is used to assess hypokinesia - slow movements, as well as a symptom such as fading when walking, which is also one of the symptoms of the disease. For this test, the user needs to stand up straight and put the smartphone in his pocket, then, after the smartphone vibrates, the user needs to go straight ahead 20 meters, then turn around and go back. The finger tapping test involves pressing the screen with two fingers: the index finger and middle finger, alternately, maintaining a constant rhythm. This test also helps to determine hypokinesia, as well as to identify a decrease in the reaction rate. In the reaction test, it is proposed to press the button on the screen and remove the finger as soon as the button disappears. The application also suggests defining a tremor during a person's actions and a tremor at rest: to do this, take the smartphone in the hand where the tremor is more pronounced, first at rest (resting tremor), then in the hand extended in front of itself (postural tremor). In addition to all the above, the application conducts a series of passive tests that do not require the interaction of the application with the user. At the same time, the application uses sensors, such as accelerometer, gyroscope, as well as magnetic field strength, GPS, WiFi parameters and phone usage logs to measure movement (for example, whether the patient has "freezing" or dyskinesia), as well as social behavior (whether the patient is mostly at home or leads an active lifestyle). This application is a very good example of integrating the capabilities of personal smartphones into the lives of people with such a serious illness as PD.

Thus, all applications that exist at the moment can be divided into 3 categories:

- applications that are designed for physical training;
- applications that provide the ability to obtain information about the PD as a whole to the user and the ability to obtain information directly from those who have already had experience solving such problems. The use of such applications is highly questionable, because today there are many websites and online reference books, and therefore there is no need to download a separate application for a smartphone.
- applications that, using sensors embedded in a smartphone, allow the user to identify and track certain symptoms.

The main disadvantages of all these applications are the lack of communication with a specialist, for example, the attending neurologist and the need to perform certain physical manipulations to assess the symptoms of PD. In addition, all existing applications for assessing the patient's condition do this with one or two parameters, for example, hand tremor (which not all patients with PD have) or voice.

In the solution below for monitoring the status in patients with PD, we tried to eliminate these disadvantages. We make a comprehensive solution that collects many parameters at once - this is the nature of using the phone, the nature of writing the text, voice, parameters evaluated using special modules such as memory, attention, reaction, fine motor skills and others. Such an extensive database allows: firstly, to accurately assess the patient's condition, secondly, to do this in the future without additional efforts on the part of the patient, to analyze what parameters most characterize the patient's condition in order to measure only them and not to measure insignificant ones parameters, in the fourth - to assess not only the condition of the patient, but also to identify the owner of the phone, in the fifth to conduct research on the possibility of early diagnosis of the disease.

3 Architecture of the information system for monitoring the status in patient with Parkinson's disease

The modules included in the system for monitoring the status in patient with PD at the current time and the relationship between these modules are shown in Fig. 2.

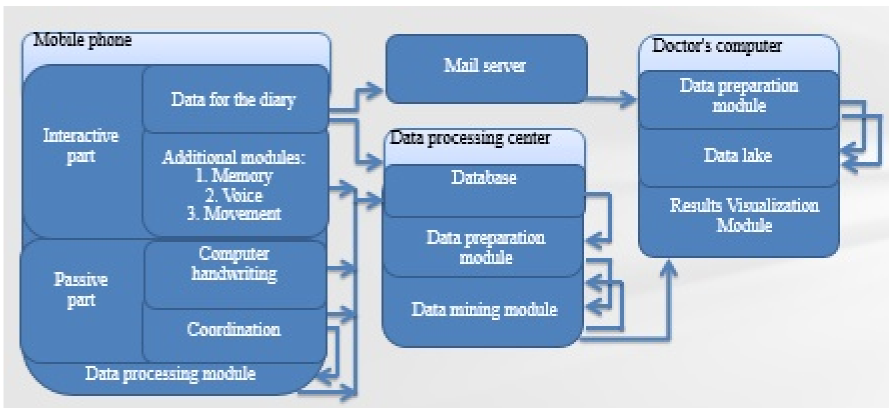

Figure 2: Architecture of the information system for monitoring the status in patients with PD

3.1 Module "Mobile Devices"

In the interactive part, the user enters information about his state. Some of this data are sent via e-mail services directly to the doctor's computer. These data are also processed on the doctor side. The amount of such data is not so much. This is due to the fact that, firstly, there is not so much data in principle that it is impossible to collect about the patient's condition without his direct participation, and secondly, the fact that the patients themselves are not ready to devote a lot of time to recording their state data. Nevertheless, these data are necessary especially at the stage of training the system as templates for testing the quality of the learning system. Sending this data to a doctor via e-mail services is not a problem. However, they are also needed in the data processing center (DPC) to create an intelligent component of the monitoring system. Since these data are recorded in the CSV format without errors, omissions and other incorrect information, they are not cleaned. On the doctor's side, this data is converted into text format, and in the data center, these data are written to the database.

As for the passive part, here it is somewhat more complicated. Data that is collected from a mobile device in a background mode (without any patient participation) can be divided into two groups:

1. data from the sensors of devices that are responsible for the movement of the phone (changing the coordinates along three axes, the angle of inclination, activity).

   These data allow to monitor the patient's activity, tremor, dyskinesia. Data is taken at intervals of one second. A large amount of data does not allow to record them in full volume in a temporary database on a mobile device and therefore they are subjected to preprocessing on a mobile device to reduce the amount of memory [16]. To do this, the application monitors the state of the phone, and the data is not written to the database at rest (when none of the coordinates of the phone's position changes), deletes duplicates, calculates the length of the rest period and writes this value to the database.

2. data collected from sensors responsible for controlling the telephone (pressing buttons, keys, moving fingers on the screen, etc.).

   This data is not cleared and processed on the mobile device. They are needed unchanged in the data center for further research. The principles of writing to the database on a mobile device of this data coincide with the first group.

Data from both groups is sent to the server either once a day, or when a certain volume is reached. This depends on the value of the membership function $\mu(x)$, for which the elements of fuzzy logic are used in the module [17]. Fuzzy sets help to work with fuzzy concepts, i.e. those that do not have the exact meaning. They change their values depending on the task. In our case, for example, the concept of "sufficient amount of data to send" is just a fuzzy concept that does not have an exact meaning.

The membership function is represented by an analytical formula and is presented graphically for clarity. To date, a very large set of various variants of membership functions has been accumulated for a wide variety of fuzzy statements [17, 18, 19]. Of course, the choice of the membership function and their parameters is largely determined by experience, intuition and other subjective factors from the decision maker. It should be noted that here we have new uncertainties that are associated with ambiguity and other kind of vagueness and which are of a subjective nature.

In the task of determining the moment of sending data from mobile devices to the server, the membership function is a combination of two separate functions "data volume" and "sending time".

Let x for the membership function "data volume" belong to the interval from 0 to 4MB. Then, as the membership function, it is possible to choose a simple piecewise linear function of the form:

$$\mu(x,a,b,c) = \begin{cases} 0, & x \leq 0 \\ \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ 1, & b \leq x \leq c \end{cases} \tag{1}$$

Since 4 MB is the maximum amount of data that can be collected per day on a mobile device (this value is calculated taking into account data types and the number of fields in Sqlite under Android OS), it is really necessary to start sending data when the data volume reaches 3.5MB.

Therefore, the graph of the membership function calculated by the formula (1) will look like this (Fig. 3).

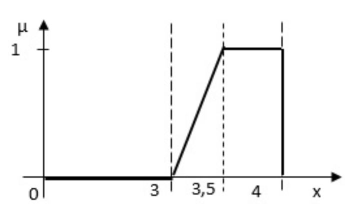

Figure 3: Graph of the membership function of the "data volume"

Let x for the membership function "sending time," belong to the interval from 0 to 24 hours. Then, as a function of membership, it is possible to choose also a piecewise linear function, the graph of which is shown in Fig. 4.

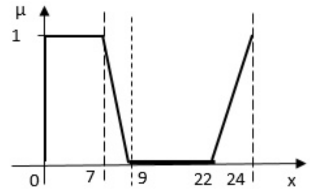

Figure 4: Graph of the membership function of the "sending time"

To determine the moment of sending the data, it is necessary to bring the functions to some uniform form. For this, the following actions were taken:

1. cyclic shift by 15 units of variable values of the function "sending time":

$$x' = \begin{cases} x+15, & 0 \le x \le 9 \\ x-9, & 9 \le x \le 23 \end{cases} \tag{2}$$

   The result is shown in Fig. 5.

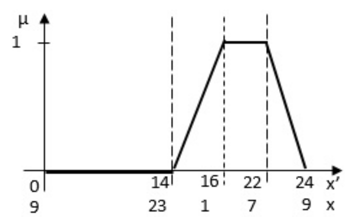

Figure 5: Graph of the membership function "sending time" after cyclic shift of values

2. the normalization of the values of variables of both functions according to the formula:

$$x'' = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{3}$$

   Graphs of functions taking into account the normalization of the values of variables are presented in Fig. 6(a, b).

3. the application of operations of intersection of membership functions (Fig. 6c):

$$\mu_{A \cap B}(x) = \mu_A(x)\mu_B(x) \tag{4}$$

3.2 Module "Data Center"

In the data center the main components are:

1. Module preprocessing data. First of all, over the primary data in the module, thera are calculated additional parameters. So according to the values of the coordinates, it is necessary to calculate the speed of movement of the phone and the periods in which the speed of movement remained constant. Here are determined the periods when there was a transfer of the phone and when the rotation of the phone. It calculates the number of no hits on the keys when typing text, pressing a

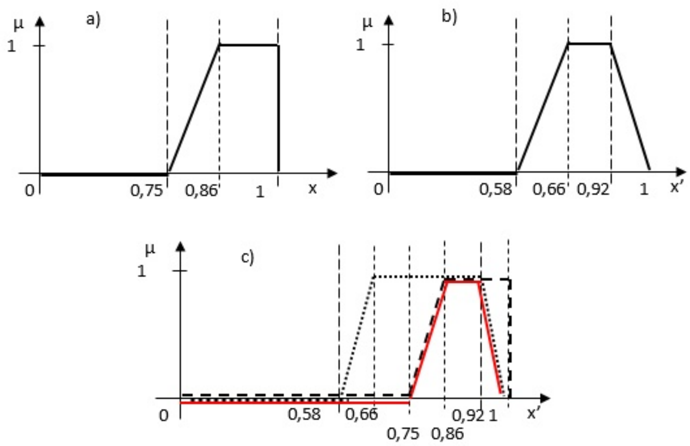

Figure 6: Graphs after the normalization operation: a) for the membership function "data volume"; b) for the membership function "sending time"; c) for the "sending" membership function after the intersection of fuzzy sets

button on the phone, incorrect touch of the fingers on the screen (for example, the user wanted to activate the screen, but no activation occurred on the first touch of the finger on the screen). This data is also recorded in the database.

2. The module of the application of data mining algorithms to obtain knowledge about the patient: the symptoms of the disease and the patient's individual handwriting. In this case, the computer handwriting of the patient in this case refers to the specifics of managing the phone, inherent in only one person. The latter is necessary for understanding:
   - are there any characteristic signs of using the phone in patients with PD;
   - does the patient hold the phone in his hands or is it done by another person. This is important because in the case of determining that the phone is not in the hands of the patient, data on its activity will not be calculated. This will make the results of the analysis of PD symptoms according to sensor readings more accurate.

3.2.1 Type of neural networks used in patient data mining

One of the main methods used in data mining is the construction and training of a neural network. In the past few years there has been a great increase in interest in neural networks that are successfully used in various fields - business, medicine, technology, geology, physics. Neural networks are used in practice wherever it is necessary to solve problems of forecasting, classification or automation. The most common are multilayer networks in which neurons are combined into layers. The most famous variant of the learning algorithm of neural network is the so-called back-propagation algorithm [20]. There are modern second-order algorithms, such as the conjugate gradient method and the Levenberg – Markard method [21], which work much faster in many problems.

The task of approximation of a function for a neural network is formed as a problem of supervised learning (training with a teacher). The essence of the problem is as follows. There are values of the function at individual points (nodes), a system of basis functions and vectors of adjustable weights. It is necessary to train the network, that is, to choose weights for the basis functions so that their combination gives a similar relationship that best approximates the set of values of the response function.

The tasks of approximation of experimental data can be solved using artificial neural networks of the following types: multilayer perceptron, networks with radial basis functions (RBF), probabilistic networks, generalized regression networks [22, 23] (GRNN).

In our study, to determine the patient's state using data from a mobile device, at least one recurrent layer must be present in the neural network, since the initial data are a function of time, and to obtain a reliable result, it is important to take into account the previous values of these functions. For this purpose, two types of recurrent networks were considered: LSTM (Long Short-Term Memory) and GRU (Gated Recurrent Unit).

The LSTM architecture was developed as an improvement on the initial version of recurrent neural networks in order to solve the problem of gradient attenuation during their training. The network is capable of storing values for both short and long periods of time [24, 25]. The LSTM block, in addition to the input and output, has a memory cell, as well as three gates that change the degree of admission or prohibition of the flow of information into the memory block and out. The input gate controls the measure of the input value in the memory, the output gate - to what extent the value in the memory affects the value at the output of the block, and the "forgetting" block - the measure of saving the value in the memory.

GRU is an alternative solution to the gradient attenuation problem. Compared to the LSTM, it does not have an output valve, so the GRU has fewer parameters. GRU is comparable to LSTM, and in some cases it surpasses LSTM in a number of tasks, such as modeling music or speech, but it has significantly worse results in a number of other tasks [26].

During testing of these networks, it was found that using LSTMs instead of GRUs leads to greater accuracy of the neural network. As a result of the work, confirmation was also obtained that with a sufficient training sample, it is possible to train the neural network so that it will return reliable analysis results.

For the implementation and training of neural networks, the TensorFlow library was used. It provides implementations of recurrence layers with optimizations for using computations on the GPU. In this case, the recurrent layers use the hyperbolic tangent as an activation function.

During the transition to a completely recurrent architecture, hidden fully connected layers were sequentially removed from the neural network. This led to a steady increase in learning outcomes without compromising productivity.

3.2.2 Applicable databases

An important aspect of any information system is the database. In our study, we are actually dealing with time series, statistics, a series of observations of the same phenomenon for some time. Each result of observation (measurement) corresponds to the time when this observation was made, or its sequence number - again, according to the time scale. When analyzing time series, not only basic statistical laws are taken into account, but also the relationship of measurements with time.

DB on a mobile device. To work with data, the Android SDK (starting with API version 1) includes the "android.database.sqlite" package [27]. The package includes classes for working with a relational SQLite database, and provides a not-so-large, fast, stand-alone, highly reliable, full-featured SQL database engine [28].

DB on the server. In our study, we used the MongoDB DBMS, which is a document-oriented database management system and stores data in JSON-like BSON documents. MongoDB, like MySQL, has index support. In this database management system, asynchronous data replication is perfectly implemented in the "master - slave" concept, and there is also the possibility of balancing the load using horizontal scaling (sharding). MongoDB can work in the MapReduce paradigm and has an analogue of the GROUP BY operator. Also, this control system operates in multi-threaded mode. The speed of

Mongo is due to the fact that the stored documents are binary and the search is based on the GridFS protocol. WiredTiger Storage Engine not only allows to work in all available streams, use all the allocated resources to increase productivity, but also performs locking at the level of individual documents. MongoDB has in its arsenal a large number of drivers (APIs) for working with almost all popular languages, but unlike MySQL, there are problems associated with the novelty of the proposed solutions, which are quickly fixed in each subsequent release. The data exchange scheme between the server and mobile phones is shown in Fig. 7

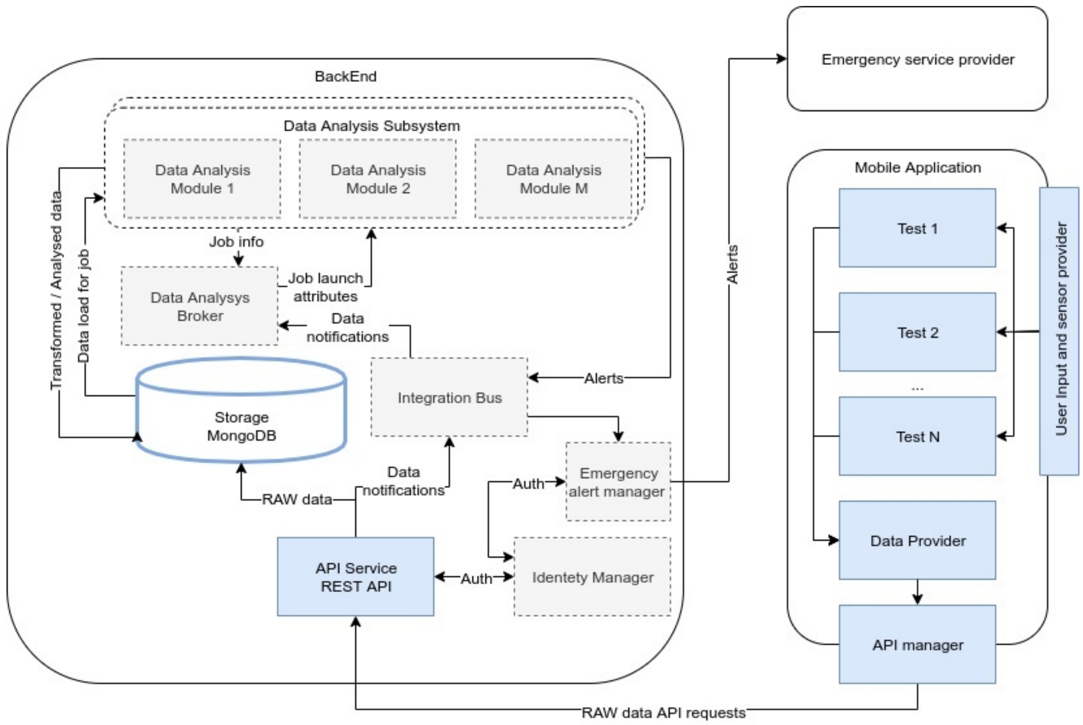

Figure 7: The data exchange scheme between the server and mobile phones

Because the data is collected practically in real time, then the amount of data on the server increases at a high speed. To speed up the data processing, we use methods of the improved KDD methodology [28] and methods of organizing multi-threaded processing of database queries. A scheme of one of the methods is shown in Fig. 8 This method allows you to create collections in MongoDB so that queries are executed as quickly as possible. This takes into account the database schema in the format of a relational model (or a set of attributes with given relationships) and a set of the most frequently executed queries The input data for this method is:

- A set of properties of objects stored in a database
- A set of fields in one table:

$$T_r = \{T_(r, j), j = 1, 2, .., n_r\}$$

- A set of all fields of a relational database:

$$M = \{T_(r, j), r = 1, 2, .., k | T_(r, j) \neq T_(q, i), \forall r, q \leq k, j \leq r_n, i \leq q_n\}$$

- A set of fields included in the queries:

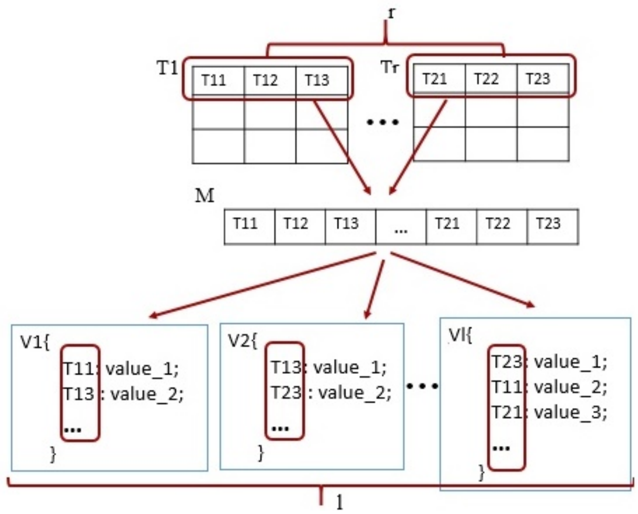

Figure 8: The DB query conversion method scheme

$$S_i = \{T_(r, j), r \leq k, j \leq r_n\}$$

The output data is a multitude of collections of documents with fields:

$$V_i = \{T_(r, j), r \leq k, j \leq r_n\}$$

satisfying conditions:

$$V_1 \cap V_2 \cap V_3 = \oslash,$$
$$V_1 \cup V_2 \cup V_3 = M = \bigcap_{r=1}^{k} T_r,$$
$$(\forall S_i)(\exists V_j)(S_i \in V_j, S_i \notin V_i, i \neq j),$$

where i is the ordinal number of collection $(i = 1, 2, l)$, l is the quantity of collections.

The method is described in detail in [29]. Because on mobile phones, on the doctor's computer and on the server of medical institutions, the data is stored in relational models that differ in their structure and set of objects and attributes, then when these data are consolidated into a single relational database, the tables are sparse. Such data can be stored more efficiently in document databases. For this reason, on a server with a system for monitoring the status of patients, all data is collected in the MongoDB database. The method presented in Fig. 8 and described in [29] allows to convert the relational model into a document model using a formalized method and select the optimal data storage structure.

3.3 Module "Computer doctor"

On the computer of the doctor, the data is converted into text format and distributed in different folders. Therefore, the storage of data on the side of the doctor is similar to the "data lake": everything is stored up to demand almost in its original form.

Thus, three levels of data processing are involved in this information system (Fig. 9).

At the first level (boundary), the data is processed on the patient's side, at the second level, the data is processed on the doctor's side and at the third level, the data is transferred to the data center for complete intellectual analysis. All three levels are interconnected.

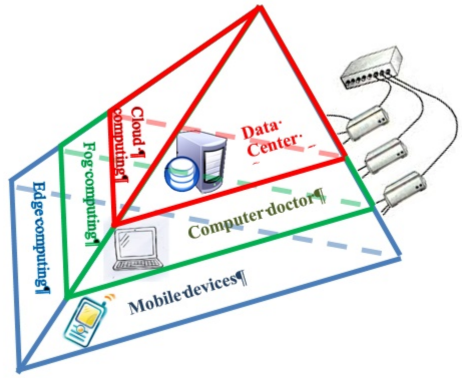

Figure 9: Three levels of processing data from a mobile device

4 Description of user interfaces of the information system for monitoring the status in the patient with Parkinson's disease

4.1 Patient Application Interface

A mobile phone application for monitoring a person's condition consists of two parts: interactive and background.

In the background, as mentioned above, data is collected using the built-in sensors of the phone. Built-in sensors can be divided into environmental sensors and position sensors. Environmental sensors are designed to collect information about the environment of a mobile phone, these include humidity and lighting sensors, a camera with a microphone. The second type of sensors include GPS, gyroscope and accelerometer.

The Android platform has several sensors that allow to track movement on the device. These sensors can be implemented in hardware or software. The sensor of gravity, linear acceleration, vector of rotation, the sensor of significant motion, step counter and step detector can be either hardware or software. Sensors Accelerometer and gyroscope are always based on the hardware. Such sensors are conveniently used to monitor the movement of a device, such as tilting, shaking, rotating or swinging. The movement is usually a reflection of direct user interaction (for example, the user controls the car in the game or the user controls the ball in the game), but it can also be a reflection of the physical environment in which the device is located (for example, to move with the user while he is driving). In the first case, tracking is carried out relative to the reference system of the device or the reference system of the user's position. In the second case, tracking is conducted relative to the world coordinate system. The motion sensors themselves are usually not used to monitor the position of the device, but these sensors can be used with other sensors, such as a geomagnetic field sensor, to determine the position of the device relative to the world coordinate system.

Using these sensors, data was collected on such parameters as:

- degree of hand tremor;
- speed of movement of users.

The interactive part includes those actions without which it is impossible to obtain information about the treatment of the disease by other ways. In particular, these include:

- recording the time of taking medication;

- recording the date when a visit to the doctor is planned;
- sending information about the patient's condition to the attending neurologist;
- setting reminders to take medication;
- input of information about medications taken, etc.

Examples of windows with which the patient has to work are shown in Fig. 10.

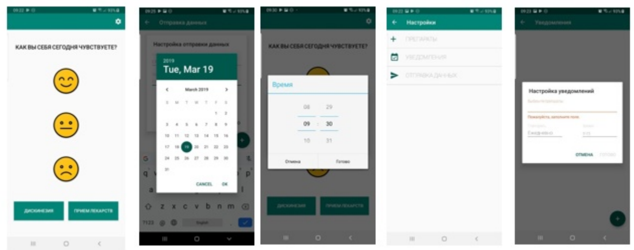

Figure 10: Examples of some application windows for the patient

This part includes an action by the patient to assess their condition. This is done to achieve two goals:

1. automate the process of making a patient diary;
2. data accumulation for neural network training.

The entire interface is designed in such a way that the patient makes as little effort as possible to study and use the application. For example, a record of the patient's condition is made by clicking on the smiley button (Fig. 10, the first window), and sending information to the attending neurologist to create a patient diary takes place automatically without patient participation the day before the visit to the doctor.

In addition, to ensure the collection of sufficient data for training neural networks, it was necessary to develop user testing modules. In the mobile application on the test page there is a list of test modules (Fig. 11), from which the user can select any test:

- A module for collecting data on the accuracy of reproduction of text by the patient, in which the user has the ability to select the text to be reprinted. As a result of passing the test, data on the text input time, the number of character deletions and the number of errors in the saved text are recorded in the database.
- A module for measuring finger motility and lateral coordination. In this module, a target is displayed on the screen (Fig. 13b), according to which in 10 seconds the user needs to press first with the finger of one, and then the second hand, as many times as possible. The countdown begins after the first touch of the target. As a result of passing the test, data on the number of touches on the target on the screen for each of the hands and the intervals between touches are recorded in the database.
- The module for measuring the patient's speech at the time of description of his health. In this module, an icon with a microphone image is displayed on the screen (Fig. 14b), by clicking on which a voice message is recorded. This test takes into account the number and time of pauses, intonation, and the volume of the user's voice.

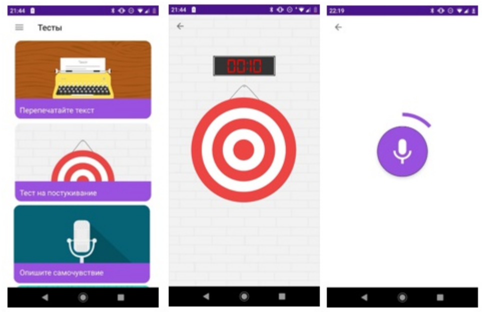

Figure 11: Examples of modules with tests

4.2 The interface of the application for the automatic creation of a patient diary

Data on the patient's condition, entered by him personally and intended to create a patient diary, are saved in a temporary "csv" file on the mobile phone. The data on the side of the phone is stored and accumulated until it is sent to the collective mail of the medical institution. After sending the data, the file is cleared.

The data file before sending is assigned a name consisting of the date of sending. The subject of the letter is automatically assigned a unique patient number, according to which the letter on the side of the doctor is automatically recognized and extracted into the appropriate folder on the computer with transformation into "rtf" format.

Application functions for automatic creation of a patient diary:

1. Parsing letters from the collective mailbox of doctors. Parsing includes: defining letters with information about the patient's condition, determining a unique patient number, extracting a file in "csv" format from mail to the appropriate folder on the computer, deleting mail from the mail server. If the folder is missing (new patient), then a new folder is created with the patient number.

2. The choice of all data recorded on a mobile device, only the data that correspond to:

   - the last three days preceding the date of a doctor's appointment. These data are necessary to assess the current state of the patient.
   - one day on which the most information in the file. Since patients often forget to record information about themselves in the application and in the diary, then these data are necessary to see the general symptoms of PD in a day.

     In addition, averaged information is provided for all days.

3. Calculation for each day of the total values of the degree of patient activity.

4. Convert the format "csv" to format "rtf", more convenient for reading and inclusion in further reports of medical workers.

An example of application windows for the automatic creation of a patient diary is shown in Fig. 12.

5 Conclusion and Future Work

Automating the process of monitoring a patient's condition with PD is an actual task. The task is especially important in view of the fact that it is necessary to collect many data about the condition in patients and it is impossible to analyze them manually. The solution proposed by the authors makes it possible

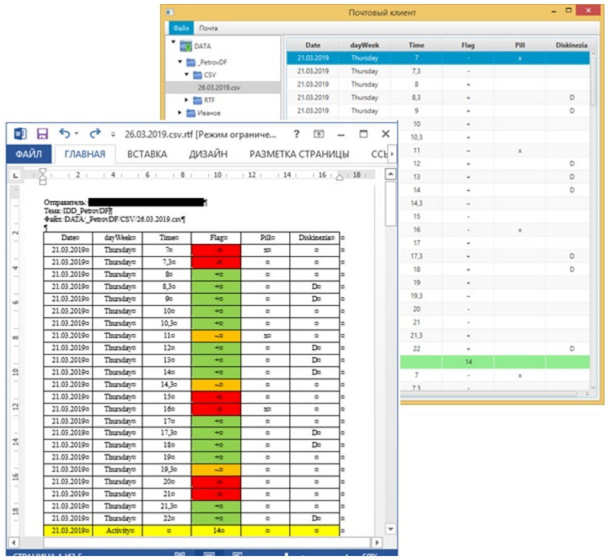

Figure 12: Examples of some windows of the automatic patient diary application

to use mobile devices for data collection. Data are collected in two modes: using direct input by users of mobile devices and in the background. They are pre-cleared and processed on mobile devices, on the doctor's computing device and in the data center. Part of the data is used to create a patient diary, and most of the data is transferred to the data center for intelligent processing. For intelligent data processing, neural networks and methods of mathematical statistics are used. The use of data mining methods is due to the need to obtain characteristics of the process of owning a telephone for identifying individuals and recording data on the patient's condition with the exception of information on unauthorized persons who sometimes get access to the telephone. The use of data mining also allows you to automate the process of filling in the diaries, to make the diary more comprehensive, to get more accurate data for the diary and to minimize the patient's participation in the diary compilation. All these solutions are designed to help doctors in improving the quality of treatment of PD, and in its earlier diagnosis. As technical solutions to speed up the process of transmitting data over the network, we used fuzzy logic methods and this allowed us to very clearly determine when the data was sent to the server depending on which limit was reached earlier: in time or in the amount of accumulated data. To speed up the data processing, we used methods for creating the optimal structure of document databases (in our case, MongoDB database) and query parallelization methods. This made it possible to use multi-threaded architectures for accelerated data processing and significantly increased the performance of the monitoring system of condition of patients with Parkinson's disease. Currently, work is being done on training a neural network to solve the problems of authenticating a phone user and classifying his state and testing of neural networks, built on individual parameters. The first results suggest that neuron networks can be used to assess the patient's condition. But, as you know, neural networks have one drawback - this is the inexplicability of the results. Therefore, neural networks are not entirely suitable for medical systems. Therefore, we also conduct research on the application of other mathematical methods, in particular statistics, multi-valued logic, and others, to search for alternative solutions in assessing the condition of patients according to the collected parameters. A further continuation of the work is to supplement the data collected with data from wearable medical bracelets, smart devices for taking medications, as well as medical information systems.

Acknowledgments

The research was funded by RFBR according to the research project #18-57-34001.

References

[1] S. Y., K. G., I. Y., and S. E., "The architecture of the system for monitoring the status in patients with parkinson's disease using mobile technologies," in *Proc. of the 2019 International Symposium on Intelligent and Distributed Computing (IDC'19), Petersburg, Russia*. Springer, Cham, October 2019, pp. 531–540.

[2] L. O.S. and F. N.V., *Parkinson's Disease*. MEDpress-inform, 2006.

[3] N. P. Foundation, "What is parkinson's?" http://www.parkinson.org/ [Online; Accessed on December 15, 2019], May 2019.

[4] T. A. A. and B. I. I., "The issues of medicalsocial expertise in parkinson's disease," 2016, [Online; Accessed on December 11, 2019] https://www.researchgate.net/publication/309026040_The_issues_of_medicalsocial_expertise_in_Parkinson's_disease.

[5] H. MM. and Y. MD., "Parkinsonism: progression and mortality," *Neumlogy*, vol. 17, no. 5, pp. 427–442, May 1967.

[6] W. H. Organization, "mhealth: New horizons for health through mobile technologies," https://www.who.int/goe/publications/goe_mhealth_web.pdf [Online; Accessed on December 10, 2019], May 2011.

[7] S. E., P. I., T. I., and D. P. G., "Mobile phone sensors in health applications," in *Proc. of the 2012 12th Conference of Open Innovations Association (FRUCT'12), Oulu, Finland*. IEEE, November 2011, pp. 19–23.

[8] W. Xu and Y. Liu, "mhealthapps: A repository and database of mobile health apps," *JMIR Mhealth Uhealth*, vol. 3, no. 1, pp. 1–9, March 2018.

[9] A. O. Elfaki and M. Alotaibi, "The role of m-health applications in the fight against alzheimer's: current and future directions," https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6131227/ [Online; Accessed on October 18, 2019], August 2018.

[10] M. Yasini and G. M. Adoption, "Use of a mobile health application in older adults for cognitive stimulation," https://www.dynseo.com/wp-content/uploads/2018/10/Etudes-DMD-StimArt.pdf [Online; Accessed on December 11, 2019], 2018.

[11] P. P., A. E., and V. M., "Intelligent mobile multimedia application for the support of the elderly," in *Proc. of the 8th International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP'12), Piraeus, Greece*. IEEE, July 2012, pp. 297–300.

[12] M. Manocha, "Finger tapping measures in parkinson's disease," http://courses.cecs.anu.edu.au/courses/CSPROJECTS/18S1/reports/u5607484.pdf [Online; Accessed on December 10, 2019], June 2018.

[13] D. Surangsrirat and C. Thanawattano, "Android application for spiral analysis in parkinson's disease," in *Proc. of the 2012 IEEE Southeastcon (SECon'12), Orlando, Florida, USA*. IEEE, May 2012, pp. 1–6.

[14] P. V., F. G., H. M., M. A., G. R., and A. R., "A smartphone application for parkinson tremor detection," https://link.springer.com/chapter/10.1007/978-3-319-13117-7_200 [Online; Accessed on December 11, 2019], pp. 785–788, October 2014.

[15] A. Zhan, M. A. Little, D. A. Harris, S. O. Abiola, E. R. Dorsey, S. Saria, and A. Terzis, "High frequency remote monitoring of parkinson's disease via smartphone: Platform overview and medication response detection," https://arxiv.org/abs/1601.00960 [Online; Accessed on October 18, 2019], January 2016.

[16] S. Y.A., D. A.B., and K. A.A., "Technology of cleaning and transforming data using the knowledge discovery in databases (kdd) technology for fast application of data mining methods," in *Proc. of the 8th International Conference on Distributed Computing and Grid-technologies in Science and Education (GRID'18), Dubna, Russia*, vol. 1787, September 2016, pp. 428–434.

[17] Z. L.A., "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338–353, June 1965.

[18] M. J.M., "Fuzzy logic systems for engineering: a tutorial," *Proceedings of the IEEE*, vol. 83, no. 3, pp. 345–377, March 1995.

[19] C. J. L. and S. J. C., "Membership functions part i: Comparing method of measurement," *International Journal of Approximate Reasoning*, vol. 1, no. 3, pp. 287–301, July 1987.

[20] D. H. and B. M., "Neural network toolbox. for use with matlab," https://www.researchgate.net/publication/2801351_Neural_Network_Toolbox_for_use_with_MATLAB [Online; Accessed on October 19, 2019], December 2000.

[21] Y. B. L., "Artificial neural network technology," *ACM SIGICE Bulletin*, vol. 15, no. 3, pp. 3–16, February 1989.

[22] B. C., "Neural networks for pattern recognition," https://dl.acm.org/doi/book/10.5555/525960 [Online; Accessed on November 21, 2019], November 1995.

[23] M. V. S. and P. V. G., *Neyronnye seti. MATLAB 6*. M.: Dialog-MIFI, November 2002.

[24] H. S. and S. J., "Long short-term memory," *Neural Computation*, vol. 9, no. 8, p. 1735—1780, November 1997.

[25] H. S., *Untersuchungen zu dynamischen neuronalen Netzen*. Institut f. Informatik, Technische Univ. Munich, 1991.

[26] C. Junyoung, G. Caglar, C. KyungHyun, and B. Yoshua, "Empirical evaluation of gated recurrent neural networks on sequence modeling," https://arxiv.org/abs/1412.3555 [Online; Accessed on November 15, 2019], December 2014.

[27] Developers, "Documentation androidḋatabaseṡqlite," https://developer.android.com/reference/android/database/sqlite/package-summary.html [Online; Accessed on December 25, 2019], 2019.

[28] Sqlite, "Official website," https://www.sqlite.org [Online; Accessed on December 25, 2019], 2019.

[29] S. Y. A. Ha V. M. and K. S. V., "Determination of the collection of collections for databases of the key-document type for a given set," *Computer tools in education*, vol. 3, pp. 15–28, 2019.

Author Biography

Yulia A. Shichkina graduated from the Tomsk State University in Mathematics in 1995. In 2005, she received her PhD in Mathematical Modeling and degree of DrSc in Computer Science in 2014. Her research interests are parallel computing, sparse matrices, and databases. She has technical skills in the fields: DB applications, operating systems, programming languages and libraries. Her list of publications contains more than 50 articles. Currently, she is a Professor.

Galina V. Kataeva Deputy Director for Research, Institute of the Human Brain named after N.P. Bekhtereva of the Russian Academy of Sciences, Candidate of Biological Sciences; Chairman of the Cognitive Research Program. The main area of research Kataeva G.V. It is mapping functions of higher mental functions using various types of functional neuroimaging, studying the neuroanatomical foundations and mechanisms of development of neurodegenerative diseases of various origins, as well as developing methods for the preprocessing of neuroimaging data.

Yulia A. Irishina after graduating from the 1st Leningrad Medical Institute named after I.P. Pavlov and clinical internship at the Institute of Experimental Medicine, worked as a neurologist at the Institute of the Human Brain named after N.P. Bekhtereva of the Russian Academy of Sciences, successfully combining medical, practical and scientific work. She is a doctor of the highest qualification category, candidate of medical sciences. She has participated in many international clinical trials. Area of interest in neurology: motor disorders. She is a member of the International Movement disorders society (MDS). He has an Honorary Diploma of the Ministry of Health of the Russian Federation. She makes the diagnosis and treatment of diseases of the nervous system and has the status of one of the leading parkinsonologists in St. Petersburg.

Elizaveta S. Stanevich is a student in the master's program at LETI "Distributed Intelligent Systems and Technologies". Her research activities are related to neural networks, solving the problems of explainability of networks and improving the quality of work of neural networks. He has practical skills in working with programming systems for the Android operating system, with databases of various types.