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Intelligent support system for e-Health

***Abstract**. e-Health is the activity with the usage of electronic information resources in the health sector and it ensures rapid access of medical professionals and patients to them. This paper presents an approach to the e-Health monitoring system development based on the IoT technologies. For such kind of system designing the Hub IoT technology and mathematical apparatus of fuzzy logic are suggested. The paper deals with the analysis of existing technologies IoT, discovered the using cloud services advantages for data processing and storage in the IoT systems (in particular IoT Hub). To improve the cloud service efficiency for data transmission and processing the approach to preprocessing data in e-Health monitoring system is proposed. This approach takes into account the software and hardware infrastructure as the common influence factor. For understanding the specificity of medical data it is proposed to use the mathematical methods based on fuzzy logic for data processing.*

***Streszczenie**. E-zdrowie jest działalnością wykorzystującą źródła informacji elektronicznych w sektorze zdrowia i zapewniającą do nich szybki dostęp specjalistom medycyny i pacjentom. W artykule zaprezentowano podejście do rozwoju systemu monitorowania portalu e-zdrowie oparte na technologiach IoT. Do projektowania tego rodzaju systemu zaleca się stosowanie technologii IoT i aparatu matematycznego logiki rozmytej. W artykule przedstawiono analizę istniejących technologii IoT i stwierdzono korzyści w stosowaniu systemów serwisów chmurowych przy przetwarzaniu danych i magazynowaniu w systemach IoT (w szczególności IoT Hub). W celu usprawnienia wydajności serwisów chmurowych w transmisji danych zaproponowano system monitorowania przygotowywania danych w portalu e-zdrowie. Takie podejście uwzględnia oprogramowanie i sprzęt infrastruktury jako wspólny czynnika wpływu. Aby zrozumieć specyfikę danych medycznych, do przetwarzania danych zaproponowano użycie metod matematycznych opartych na logice rozmytej. (**Inteligentny system wsparcia dla portalu e-zdrowie**)*

Keywords: Internet of Things; e-Health Systems; IoT Hub; Fuzzy Logic; Fuzzy Knowledge Bases; Computerized diagnostics system.
Słowa kluczowe: Internet rzeczy, systemy e-zdrowie, IoT Hub, logika rozmyta, bazy wiedzy rozmytej, skomputeryzowany system diagnostyczny

1. Introduction

Internet of things technology (IoT) is penetrating into everyday life increasingly through the implementation of e-Health technologies, e-society, e-city, etc. The widespread implementation of IoT technologies associated with a number of difficulties, determined by a combination of factors.

One of the factors hindering the widespread implementation of IoT technologies, in particular in the field of e-Health, is the factor that is associated with features of the software and hardware infrastructure: a large heterogeneity of hardware devices resources (CPU power and available memory), software (operating systems, application software) and the heterogeneity of the communication interfaces.

Another complicating factor is the specific character of the medical data, the essence of which lies in the processing of large data volumes and the need for constant monitoring (in short time intervals) to cause additional processing load.

E-Health monitoring systems designing should take into account the resource constraints of the user receiving device, the possibility of interruption, the possible presence of unreliable data channel, the security and compatibility of different software platforms.

The paper deals with the e-Health monitoring system development based on the IoT technologies. To improve the cloud service efficiency during data transmission and processing the approach to preprocessing data in e-Health monitoring system is proposed. This solution takes into account as the software and hardware infrastructure influence. For understanding the specificity of medical data the mathematical methods based on fuzzy logic for data processing are used.

2. Background and related works

Intelligent e-Health monitoring systems are implemented intensely because of the diagnosing patients process is characterized by reliability and efficiency of decisions taken by the doctor. Already from the middle of the 20-th century the computerized diagnostic and treatment centers began to operate in hospitals where a powerful material base for the introduction of advanced intelligent technologies were presented [1].

2.1 The first computerized diagnostics systems

Information about the first Ukrainian and foreign computerized diagnostics systems are presented in Table1.

Table 1. Appointment of expert medical computerized diagnostics system of e-Health

Name	Description
AAPHelp	Expert system for diagnosing diseases of the abdominal cavity
INTERNIST I	Expert rule-oriented system for diagnosing internal diseases
MYCIN	Expert system for diagnosing diseases of the blood, one of the most famous, has many additions and extensions
CASNET/Glaucoma	Expert system for diagnosing glaucoma

The main functions of the computerized diagnostics system are:

• administrative - support the process of diagnosing and related with this process information;
• management – regulation of diagnosis and analysis phases;
• controlling - monitoring and evaluation of all study phases;
• maintenance – support decision making process by specialists, provide treatment recommendations based on the diagnostics results;
• synthesis - associated with the decision making process to get its interpretation.

The main disadvantage of these systems are the difficulties of implementation in practical public health, the need to attract highly qualified specialists and experts to form a knowledge base. This is very complex process [5]. Also, e-Health monitoring systems designing should take into account the considerable heterogeneity of hardware resources and the heterogeneity of software and communication interfaces. The additional problem for e-Health monitoring system development is arising from the medical data specifics, namely its large volumes and the need for the patient monitoring continuously. There are two main roles in the e-Health monitoring system: the patient and the person who receives the processed data. The patient and the person who receives the processed data can locate in no reliable data transfer zone or use unreliable data channels. Therefore, e-Health monitoring systems development should take into account the user receiving device constraints, the possibility of interruption, the possible presence of unreliable data channel, the security and compatibility of different software platforms.

2.2 The approach to e-Health monitoring system designing based on of fuzzy logic

Data processing in e-Health monitoring system consists of the following stages: gathering raw data, data cleaning from the anomalies. Cleaned data are going via classification block which groups and forms data into semantic groups. After that, the data are sent to the user. This processing unit is designed to handle small amounts of data, but this approach is not suitable for processing large amounts of data because the data can't be clearly interpreted and processing algorithms become fuzzy. That is why upgrading processing unit uses the following stages of data processing (Fig. 1)

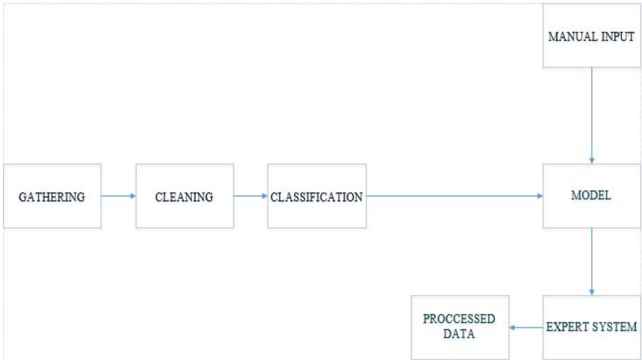

Fig.1. An approach to the block of decision-making for e-Health monitoring system developing

Available unit generates the models that represent existing and classification data. These data are formed with the meta-descriptions automatically. Manual input block allows the expert to introduce reliable data, correct data model thereby improve them. The expert system is formed after the process of the model manual input and configuration. The user gets the processed data using the expert system which is based on fuzzy logic inference algorithms. This data are preliminary diagnoses or conclusions concerning the human health. The main advantages of proposed approach to e-Health monitoring system data processing are the ability to process large amounts of data and to correct using the bandwidth of the communications systems by reducing the amount of data transmitted via the network.

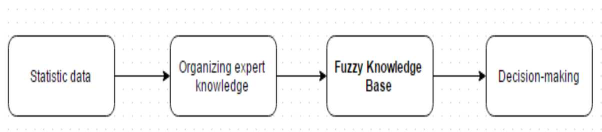

Fig.2. Stages of decision making process based on fuzzy logic

In many systems with a large amount of statistic data the expert solutions for the data processing are used. However, the approaches associated with expert solutions are characterized by fuzziness. In this regard, it is proposed to use the mathematical apparatus of fuzzy logic. This apparatus gives the possibility to realize decision making process based on models that are close to the human thinking (Figure 2). Decision-making systems based on fuzzy logic are characterized by the simplicity of the decision-making process, especially with tree structures and the ability to analyze alternatives.

The e-Health system for monitoring health parameters was developed based on Mamdani type fuzzy model that solve the problems of extracting knowledge from data (in the form of linguistic rules) and the associative links searching in the data set [8]. The important advantage of such models is the correct interpretability of data subject. The disadvantage is associated with a complexity of doing fuzzy inference to compensate by means of powerful servers in the cloud and IoT Hub technology.

3. Fuzzy logic decision-making algorithm

For decision-making process based on fuzzy logic it is proposed to use the process structure identification – the definition of the fuzzy systems structural characteristics such as the number of fuzzy rules, the number of linguistic terms. They forms two groups of the structure identifiers. This identification is performed by fuzzy cluster analysis or busting method.

The usage of cluster analysis algorithm is directed to the separation of the total population into clusters so that each of them are the most similar objects properties. Fuzzy clustering is one of the most interesting methods of identifying and testing the possible data structure hypotheses groups. The methods of fuzzy clustering allow the same object belong to several clusters at the same time but with different degree of accessories. Typically, each cluster is characterized by some prototype which is described by the center of the cluster and some additional information, for example, size and shape of the cluster. There are many clustering techniques. In this paper is presented the algorithm of fuzzy c-average [6].

The input data for the algorithm of fuzzy c-average are presented in the observations table. The initial data are used for clustering of the observations table data presented as shown on table 2.

Table 2. The observations table

Temperature	Pressure	Pulse	Level of health
37	120/70	67	5
38	130/60	75	4
38	150/40	80	2
37	120/70	67	5

Mathematically the data presented in the table 2 can be described:

The table: $T = \{t1, t2, ..., t_M\}$,

where k is the element of $t_k = (x_k, y_k)$,

$x_k=[x_{k1}, x_{k2},\dots,x_{kn}]$ – the vector of the input values,

y_k — the output value,

M — the number of observations,

n — the number of the input variables,

$x_k \in DX$, $y_k \in DY$.

Let $P(T)$ — the cardinality of T set that is the set of all subsets of T.

The fuzzy c-partition of T is the set of

$\{A_i|A_j \in P(T),\ 1 \le i \le c,\ 2 \le c \le M - 1\}$, c — the number of the clusters.

The clusters are characterized by the matrix of fuzzy partition $F = [\mu ki]$, which has the following properties:

(1) $$\forall_{K=\overline{1,M}}\left(\sum_{i=1}^{c}\mu_{ki}=1\right),\forall_{i=\overline{1,c}}\left(0<\sum_{i=1}^{c}\mu_{ki}<M\right)$$

C-fuzzy algorithm is based on minimizing the average distance from the observed data to the cluster centers.

The Euclidean distance is calculated by the formula:

(2) $$\sum_{i=1}^{c}\sum_{k=1}^{M}(\mu_{ki})^m \| v_i - t_k \|^2$$

where

(3) $$v_i = \sum_{i=1}^{M}(\mu_{ki})^m t_k \sum_{i=1}^{M}(\mu_{ki})^m t_k \Bigg/ \sum_{k=1}^{M}(\mu_{ki})^m$$

— the vector of the fuzzy cluster centers, $m \in [1, \infty)$ — the empirical number, usually equal to 2.

The algorithm of fuzzy c-medium proposed in the papers [6] is implemented for fuzzy decision-making process realizing into the e-Health monitoring system. The main steps of algorithm are follows:

Input data: The input data are presented by table observation *T,* there are the number of clusters*,* the number of *m* and the stop parameter *ε.*

Output data: The output data are presented by fuzzy partition matrix *F* and cluster centers *V.*

Algorithm:

Step 1. To initialize the matrix of fuzzy partition *F* satisfied the conditions *(1)* randomly.

Step 2: To compute the vector v_r - the clusters centers.

Step 3. To calculate

1) the distance d_{ki} between k and the matrix *T*,

2) *i-th* cluster center $d_{ki} = \sqrt{t_k - v_i}$.

Step 4. To calculate the next approximation of the matrix *F;*

(4) $$if\ d_{ki} =>, then\ \mu_{ki} = \left(d_{ki}^2 \sum_{j=1}^{c} \frac{1}{d_{kj}^2} \right)^{\frac{-1}{(m-1)}}$$

(5) $$if\ d_{ki} = 0, then\ \mu_{ki} = \begin{cases} 1, j \neq i \\ 0, j = i \end{cases} \quad j = \overline{1, c}$$

Step 5. If $||F—F||^2$, output of the algorithm, otherwise, go to step 2.

Here F* — the partitioning fuzzy matrix derived into the previous iteration of the algorithm.

As a result, the algorithm calculates the centers of the clusters matrix

$V = \{v_1, v_2, ..., v_c\}$, where

$vk = \{v_{k1}, v_{k2}, \ldots, v_{kn}, v_{kn+1}\}$, v_{ki} the coordinate value of *i-th* variable in *k-th* cluster,

v_{kn+1} — the coordinate value of the output variable in the *k-th* cluster.

The each cluster corresponds to the one dedicated linguistic rule of fuzzy knowledge base system. The each linguistic term is located in the antecedent fuzzy rules given their membership function. As membership function Gaussian type function is selected. It is presented by the formula (6):

(6) $$\mu(x) = \exp\left(\frac{(x-a)^2}{2\sigma^2} \right)$$

Based on the results of cluster analysis, it is possible to determine the parameters of the membership function as follows:

$$a = v_{ij}$$

$$\sigma_{ij}^2 = \frac{\sum_{k=1}^{M}(\mu_{kl})^m (x_{ki} - y_{ij})^2}{\sum_{k=1}^{M}(\mu_{ki})^m}$$

The fuzzy knowledge base forms after the necessary parameters determining and the membership functions designing. The fuzzy concept $LX_{i,k}$ in the rules (1) and (2) corresponds to the statement «X_i is approximately equal v_{ij}». General view of the knowledge rules for Singleton models type looks like the following:

(7) R_j*:*$X_1 \approx v_{j1}$ *AND … AND* $X_n \approx v_{in} \rightarrow v_{jm+1}$*,*

For Mamdani model – R_j*:*

(8) $X_1 \approx v_{j1}$ *AND … AND* $X_n \approx v_{in} \rightarrow y \approx v_{jm+1}$*,*

where v_{ji} – the value of the coordinate *i-th* input value in *j-th* cluster,

v_{jn+1} — the coordinate value of the output variable in *j-th* cluster, $1 \leq j \leq$ c.

Thus, the proposed algorithm solves the problem of the linguistic terms determining and the fuzzy rule base formation [6].

There is not only one possible approach to use the Gaussian membership functions for the fuzzy rules formation. The transformation from Gaussian functions to triangular, trapezoidal and parabolic methods and algorithms are described in works [6].

An advantage of the algorithm is the partitioning algorithmic input space into a fixed number of clusters and hence a fixed number of terms and rules. The disadvantage is the absence of guarantee that the input space is represented by cluster centers properly.

4. The IoT-based approach to e-Health monitoring system development

For e-Health monitoring system development based on the IoT Hub node is suggested. This approach has the some advantages over the earlier the IoT services such as Eventhub and service bus [1]. The Hub is able to receive messages from the device to the cloud-based service (telemetry communication, feedback) and to send messages and commands from device to cloud services. It allows to manage, monitor and connect a huge number of devices supporting HTTP, AMQP and MQTT protocols. The libraries for developers are available for several platforms such as Windows, Linux and some real-time OS, support for multiple languages such as C, .NET, Java and Node.js. The data processing and storage systems designing based on the script for the IoT Hub using to connect devices to cloud-based service and provide two-way communication (device - cloud services, cloud services - devices). The messages between devices and cloud services are stored securely and authenticated. The proposed architecture with an additional IoT Hub node provides the ability to process millions of requests per second. IoT Hub also provides authentication for each device and guarantee a secure connection.

4.1 System architecture

On fig.3 e-Health monitoring system architecture is presented. The system architecture is based on IoT Hub and consist the following elements:

1) S1, S2, S3, S4 - the set of the sensors.

2) Transfer Center – serves as a device that transmits data from all the sensors to IoT Hub simultaneously.

3) IoT Hub - provides the ability to exchange messages between devices and cloud services, as well as processing as a gateway to the cloud and the unit provides other key services IoT Suite.

4) Event processing module Azure Stream Analytics provides fast date analysis. It is used for the telemetry data aggregation, for the incoming data stream processing and event detection.

5) It is possible to use BLOB-configured objects, Queue-, SQL-, table- Storage.

6) VM (Virtual Machine) is the virtual machine for knowledge extraction based on the fuzzy logic algorithms, sampling and data analysis with BLOB-objects, Queue-, SQL-, table Storage.

7) Date visualization is available by means of Azure Web applications and Microsoft Power BI using which are configured for the virtual machine.

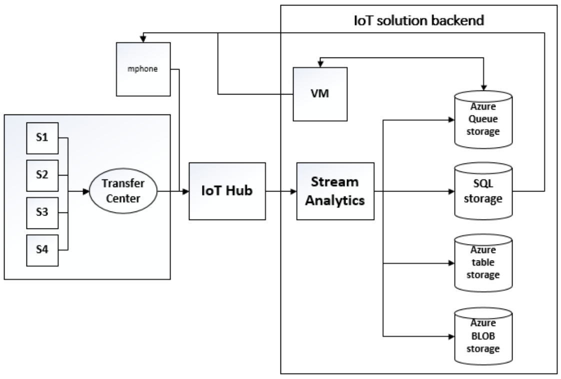

Fig.3. The e-Health monitoring system architecture based on IoT Hub

4.2 Data processing scenarios

Primary data are collected from sensors that are located on the human body. Carrying out the parameters measurements of several times a day they transmit the numerical values of parameters such as body temperature, blood pressure and pulse rate to the server for data processing. According to the proposed approach a fuzzy inference based on the values of these parameters is carried out on the server. As the result (instead of the input data type: temperature: 37°, pulse 60 beats/ min, pressure: 120/70) there is the possibility to get a conclusion at the output (the human condition: normal). Fig 4 presents this example.

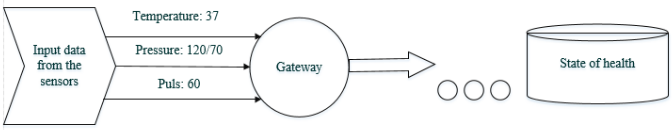

Fig.4. Data processing example using the apparatus of fuzzy logic

Fuzzy inference is based on the rules such as IF-THEN. In these rules the numerical values of the input parameters are changed by their terms - text values that characterize the relation between the possible numerical values of the parameters. For the above example the set of rules will look like this:

1. IF <a person has normal temperature> AND <the pressure is increased> AND <the pulse is normal> THEN <the level of health is normal>
2. IF <a person has increased temperature> AND <the pressure is normal> AND <the pulse frequently> THEN <the level of health is poor>

Thus obtained parameters via sensors (temperature: 37°, etc.) are converted into relevant terms. For example, a common scale of the possible human body temperature - 37° is level of value to correspond with the term "above average". The set of rules requires the pre-generated logic inference by expert given which is its own assessment of the normal parameters values for it. Number of the rules should not be large because the fuzzy logic algorithms are able to make decisions based on even a small sample of the input data; however, the number of rules in system increasing enhances output accuracy.

After passing through the fuzzy inference procedure it is transferred for the user presentation only one value - for this example, a text string "normal" which is recorded on the server database in the field named "level of human health." It is not necessary to transmit the name of the resulting network parameter (database field name - the term "human health") because this information is not dynamically changeable and the characteristic of the human condition is described by only one integrated complex parameter. Ambiguities are absent in the database.

Thus, the amount of data transferred over the network for the long distances (from the server where the data processing is performed to the user) are reduced significantly (Figure 4). If the resulting value takes a negative result the pre-configured system sends the message to the nearest hospital or clinic, informs relatives automatically.

5. Conclusion

This paper presents an approach to the e-Health monitoring system development. The distinctive features of this system are as follows:

1. The data collection subsystem is designed based on IoT Hub technology and has the advantage of incoming data controlling with the ability to reject data that come from unauthorized devices.
2. The data processing subsystem is configured in cloud and uses fuzzy logic to obtain a more accurate result.
3. The data transmission subsystem based on IoT Hub technology allows to manage a number of heterogeneous networks including multiple devices, which have limited resources.
4. IoT Hub is used by external clients without any prior knowledge about the implementation details (communication protocol and IP-address) and is able to manage a number of heterogeneous physical networks with multiple devices with limited resources.

The future work is connected with the clustering algorithms improvement by reducing their sensitivity to noise and emissions data as well as more efficient usage of distributed architecture in e-Health monitoring systems.

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