glucose concentration, telemedicine, artificial organs

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THE REMOTE CONTROL SYSTEM OF THE INSULIN LEVEL

The following research characterises the system for remote data collection of blood glucose concentration. Based on the data an algorithm was introduced in order to determine the infusion of insulin. This paper presents a glucose measurement method using the test strips, instructions for collecting the source data, as well as the process of adjusting the insulin dosage.

1. THE INTRODUCTION

The main goal of the following study is to create a separate wavelet-neuron structure which would reflect the patient's glucose profile curve received as a result of the blood glucose measurement. The successive aim is to construct an artificial pancreas model on the basis of the telemedicine and the AI algorithms. Its main elements are: blood glucose measurement device based on the reflectance converter adapted for the dry tests Accutrend, artificial intelligence as a decision-making element, as well as characterization of the available applicators and insulin pumps as the closing elements of the glucose-insulin feedback system. Medium combining all these elements together is the application in the Internet which collects all the necessary data for calculations.

2. THE METHOD

The wavelet signal representation s(t) is a relatively new method. There are not many studies based on this method. The artificial pancreas model development as well as glucose-insulin system simulation with the help of the wavelet signals representation is a complete novelty. Studies which apply to this subject matter are:

- Simulation of glucose-insulin model implemented in SIMULINK, Brown [1],
- Creating adaptive controllers for intelligent monitoring of diabetic, Bellazzi [2],
- Constructing a subcutaneous insulin absorption model, Nucci [3],
- Study about the control of drug delivery to a patient, Doyle, Parker [4],
- Model pancreas function during a long-term insulin therapy, Young, Chuang [5],
- Kinetic model of blood glucose variation in a bioartificial pancreas, Young [6],
- Development of the insulin-glucose feedback model, Tolic [7].

In Poland the issue of artificial pancreas has been raised in the studies of Nałęcz [8], Świercz [9], Ładyżyński [10] as well as Trojanowski and Wach [11, 12, 13].

There have been used different methods of modelling the insulin-glucose system based on the AI algorithms in the aforementioned publications; however, none of the known studies has tried approximation and modelling with the use of wavelet neuron networks.

Construction of wavelets in the MATLAB environment by the 'wavemngr' function.

Arguments of the function 'wavemngr' ('add', FN, FSN, WT, NUMS, FILE, B) are:

- FN – full family name,
- FSN – short name of the wavelet family,
- WT – wavelet type,
- NUMS – the definition of the wavelet,
- FILE – adds a new wavelet to the MATLAB set,
- B – number of trials in a given wavelet.

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As a result of this research based on 2600 measurement, 51 ‘own’ wavelet functions have been distinguished which demonstrate the features of the insulin-glucose system.

Characterization of the glucose profile curve seemed impossible. It’s a very variable process which depends on many factors like diet, time, metabolism, lifestyle, work and many others. In order to take into account as many features as possible, 2600 measurement points have been analyzed. Furthermore, 200 most characteristic processes from among them have been selected. The main task of wavelet restructuring was to define the feature vector which would be influenced by the learning process. Feature vector could be determined thanks to the previously characterized wavelet functions:

- Haar wavelet,
- Coiflets
- Biorthogonal,
- Symlets,
- Alternative function “diab”.

The experiments were unsuccessful as the prediction for the diabetes support system had not been received.

Feature vector is the first part of the classifier system where the results of dry tests are being exposed to the wavelet decomposition for N-factors and ai scale defined with the wide range of analyzed data.

An alternative solution has been prepared and wavelets called ‘diab’ have been designed. As a result N wavelet components have been received which correspond with the subintervals set in the bounded interval with endpoints among parameters from scale ai. Feature vector Fihas been received for the neuron net.

3. THE PROJECT

In order to collect the necessary data a special web site was created, namely http://virtual-net.pl/DiabLab/personData.html. On the web page a patient is supposed to write his or her weight, age, gender and of course the level of blood glucose concentration obtained by the strip test method. Furthermore, the system saves the data and enables the patient to view the history of measurements. There is also a possibility to refresh the results. After having collected the necessary data, the system will determine the required amount of insulin, as well as the blood glucose curve.

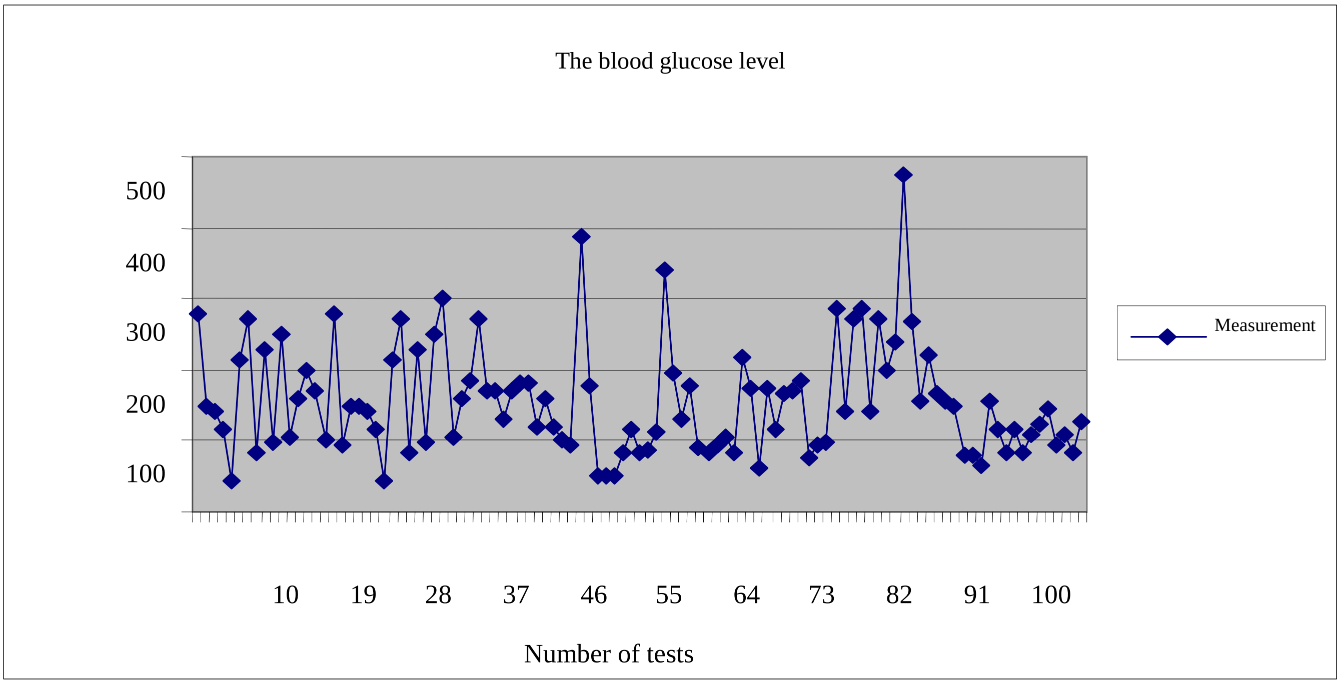


Fig. 1. Graph of the blood glucose level within given time periods for the research trial of 56 patients.

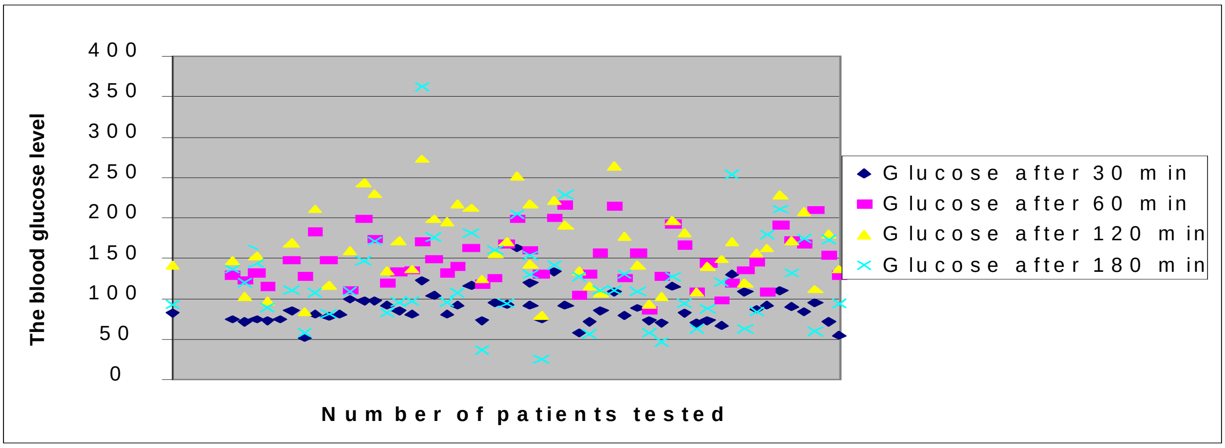


Fig. 2. The graph of the patient's glucose profile curve.

The results, which have strictly a research character, are based on the trial of 56 patients from different age groups. The important point of analysis is also the fact that the blood glucose level was monitored several times a day during the whole week in order to establish the right doses of insulin for every patient.

The results suppose to identify the problem and find the best solution for the patients. Therefore, three different methods were specified: proportional-differentiating relation, Fourier analysis and AI algorithm method.

3.1. THE AI METHOD

The IT system which facilitates the decision making process has been constructed in such a way that it would be available twenty-four hours and seven days a week for every Internet user. One of the most important aspects of the IT system is the possibility of continuous patient's monitoring with the assumption that the more data you have, the better reliability of the system. Another essential feature of the system is a clear web page where text mode is more important than the graphic one. Thanks to the web page a patient has got an access to the data base with the daily glucose level. The server environment for the application is Apache/2.2.9.

The elements that influence the decisions of the system are two neuron networks. The first one activated by the 'diab' wavelet family affects the decisions of a doctor by identifying diabetes on the basis of 2600 measurements of blood glucose level. The other one defines the necessity for insulin infusion based on 56 diabetes trials on patients with diabetes.

The IT system was tested on equipment with platform Intel Core Duo2 T7250 and 2GHz, stroke of main bus 777MHz, 1GB memory RAM.

3.2. THE RESULTS

System proved the following interrelations during the tests based on 2600 data from patients with diabetes:

Test in diagnosing diabetes for 100 randomly chosen cases among 2600 measurements.

Table 1. Results of diabetic transforms diagnose system activated by an alternative wavelet and neuron network activated by polynomial function and Fourier transform.

Approximation	Fourier transform	Polynomial	"Diab" wavelet
Diagnosis	49	71	75

The model 1 – approximation by Fourier transforms:

$$f(x) = a_0 + a_1 * \cos(\omega x) + b_1 \sin(\omega x) \qquad (1)$$

where:
a_0 = 133 (-399.5, 665.5)
a_1 = -15 (-816, 786)
b_1 = 0 (-5.622e+018, 5.622e+018)
ω = 0.1047 (-1.995e+015, 1.995e+015)

The model 2 – approximation by polynomial:

$$f(x) = ax^3 + bx^2 + cx + d \qquad (2)$$

where:
a = 5.426e-005 (-0.0001022, 0.0002107)
b = -0.02401 (-0.06649, 0.01847)
c = 2.509 (-0.4938, 5.512)
d = 89.92 (37.22, 142.6)

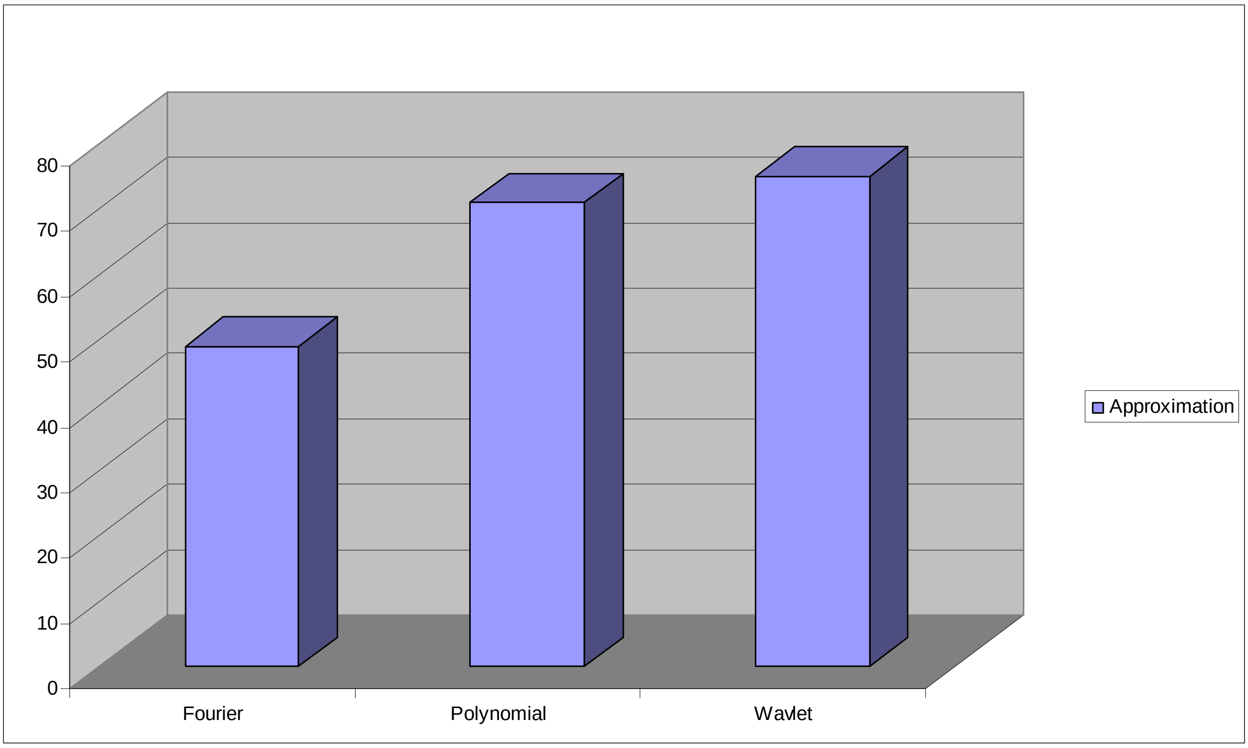


Diagram.1. Results of analyzing diabetic transforms diagnose system activated by an alternative wavelet and neuron network activated by polynomial function and Fourier transform.

Test verifies high efficiency of the system [SN] activated by an alternative ‘diab’ wavelet or polynomial. System [SN] released by the Fourier function proved recognizability on the level 49 from 100.

Test determining the necessity of infusion for 56 measurements from the data base.

Table 2. Results of diabetic transforms diagnose system activated by an alternative wavelet and neuron network activated by polynomial function and Gauss function.

Approximation	Gauss function	Polynomial	Data from diabetic test
Diagnosis	18	11	38

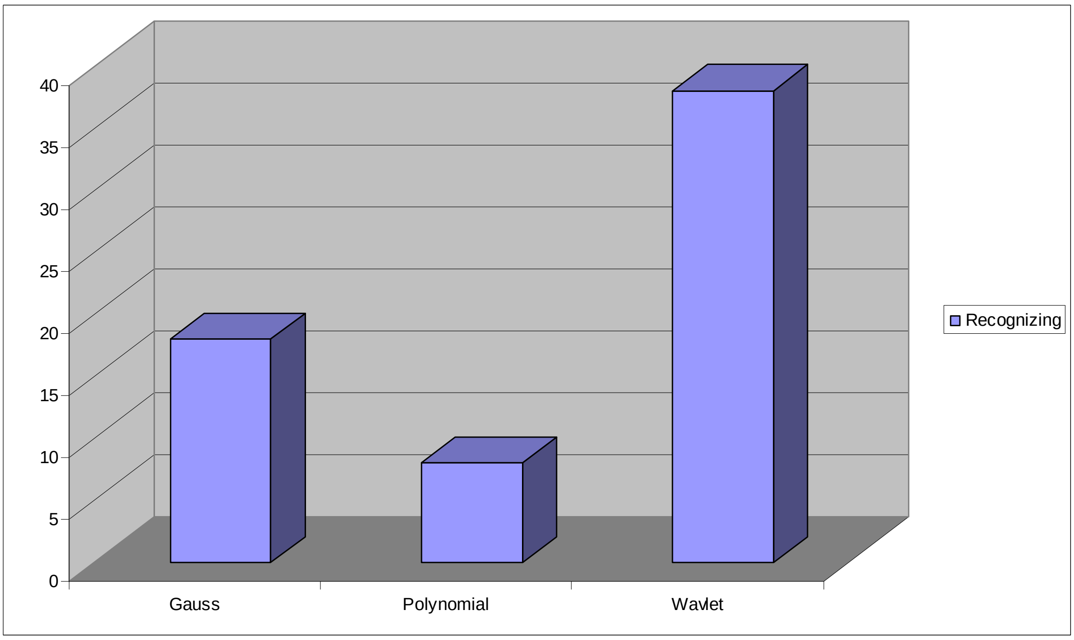


Diagram 2. Results of analyzing diabetic transforms diagnose system activated by an alternative wavelet and neuron network activated by polynomial function and Gauss function.

Diagram 2 presents superiority of the system activated directly from the data base of blood glucose measurements where among 56 diabetic cases the system verified it 38 times.

During the simulation of blood glucose profile and diabetic transforms with the help of neuron and neuron-wavelet network there was a search for an optimum relative to the value:

Amount of iterations of networks learning

Number of hidden networks

Operation time

Above-mentioned equipment was able to perform about 150 000 iterations during one day. Tables (1) and (2) as well as diagrams (1) and (2) present arrangement of MSE (Mean Squared Error) for the test and for blood glucose profile.

Table 3. Acceptance or rejection the learning cycle for the diabetic test.

	Number of ite	1000	2000	5000	10000	50000	100000	500000	1000000
Levels of neural network_1									
5		Fail	Fail	Fail	Fail	Fail	Pass	Fail	Fail
10		Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass
15		Fail	Fail	Fail	Pass	Pass	Pass	Pass	Pass
20		Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass
25		Fail	Fail	Fail	Pass	Pass	Pass	Pass	Pass
50		Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass
100		Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass
150		Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass
200		Fail	Fail	Fail	Fail	Pass	Pass	Fail	Pass
250		Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass
500		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
1000		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail

Table 4. Acceptance or rejection the learning cycle for the blood glucose profile.

	Number of itera	1000	2000	5000	10000	50000	100000	500000	1000000
Levels of neural network_1									
5		Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass
10		Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass
15		Fail	Pass	Fail	Pass	Fail	Pass	Pass	Pass
20		Fail	Fail	Fail	Fail	Fail	Pass	Fail	Pass
25		Fail	Fail	Fail	Fail	Pass	Fail	Fail	Fail
50		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
100		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
150		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
200		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
250		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
500		Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail

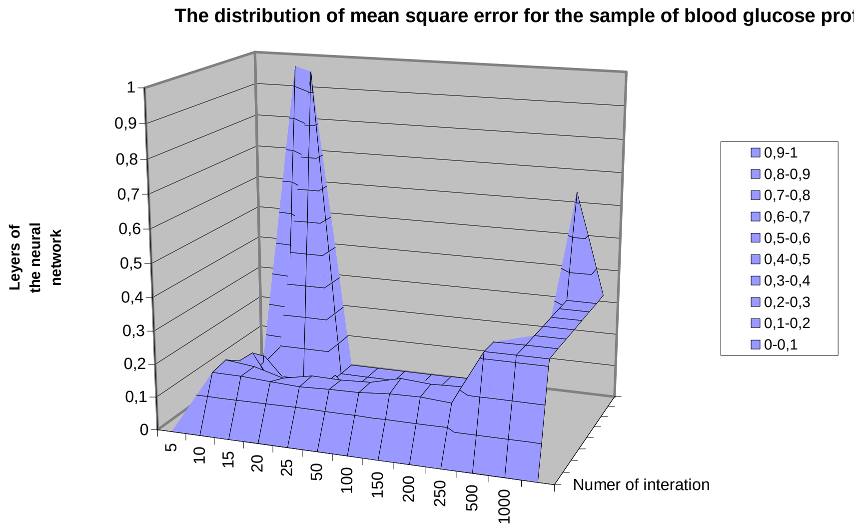


Diagram 3. Arrangement of MSE for the diabetic test depending on the amount of hidden neuron networks and the number of iterations of learning networks.

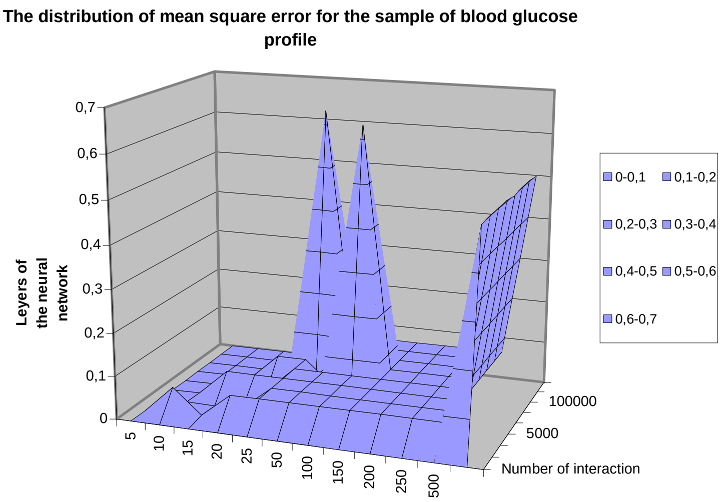


Diagram 4. Arrangement of MSE for the blood glucose profile depending on the amount of hidden neuron networks and the number of iterations of learning networks.

4. THE CONCLUSION

A number of empirical researches have been conducted. The most important one was comparing approximation of a characteristic transform for a patient with diabetes. A data base of the blood glucose level indications has been collected for diverse patients. Features of transforms in the above mentioned groups of data have been examined and on the basis of that types as well as characteristic features of transform approximation have been chosen.

Thanks to the standard wavelet algorithms ‘diab’ alternative wavelet has been prepared. Neuron network structure, which reflects the pancreas function and supports the possibility of diagnosing diabetes, has been derived for the ‘diab’ alternative wavelet.

Principles for the IT system of artificial pancreas have been prepared, and IT system within the WWW has been implemented.

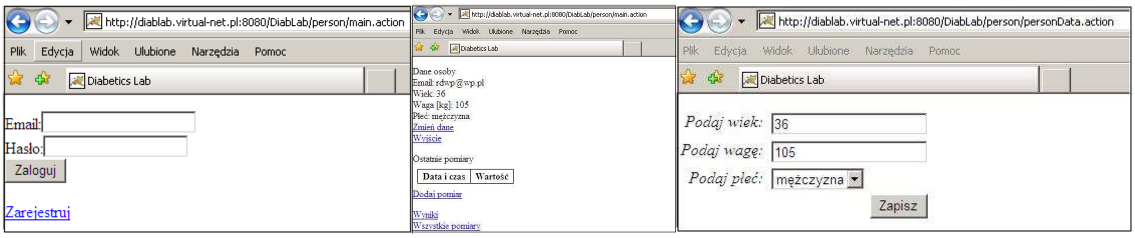
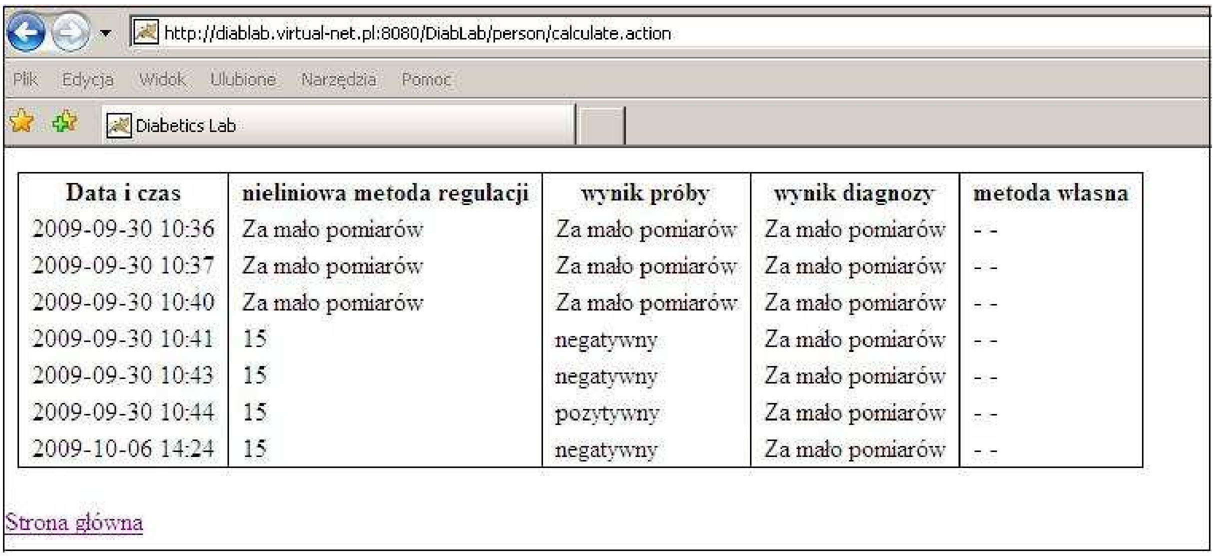


Fig. 3. Window of data change in the artificial pancreas system (in Polish).

The artificial pancreas algorithm has been worked out as a supporting system for a diabetologist. It enables to make decision when it comes to the amount of insulin infusion. System is for healthy patients as well as for those with diabetes, however, the second group should always consult with the doctor. In such case, system can be used as a register for the patient as it allows daily monitoring of the blood glucose level and the disease itself.



Data i czas	nieliniowa metoda regulacji	wynik próby	wynik diagnozy	metoda własna
2009-09-30 10:36	Za mało pomiarów	Za mało pomiarów	Za mało pomiarów	- -
2009-09-30 10:37	Za mało pomiarów	Za mało pomiarów	Za mało pomiarów	- -
2009-09-30 10:40	Za mało pomiarów	Za mało pomiarów	Za mało pomiarów	- -
2009-09-30 10:41	15	negatywny	Za mało pomiarów	- -
2009-09-30 10:43	15	negatywny	Za mało pomiarów	- -
2009-09-30 10:44	15	pozytywny	Za mało pomiarów	- -
2009-10-06 14:24	15	negatywny	Za mało pomiarów	- -

Fig. 4. Window of decisions in the artificial pancreas system (in Polish).

Programmer equipment has been chosen within the public license which is available thanks to the Open Source Definition so that the costs of maintenance and implications could be as low as possible. Therefore, system maintenance consists of payments for domain and service. What is more, in order to cut costs a potential user needs an Internet access from device using standard browsers without license:

Mozilla/5.0, Firefox/2.0.

MS Internet Explorer minimum 5.0. version.

and other browser systems available on mobile phones of the most popular companies in Poland.

The costs of a patient are equivalent to the bought equipment as producers of computers and mobile phones equip it already with operating systems and Internet browsers. This solution is in author's opinion optimal from the economical point of view. An alternative would be to use paid licenses on SQL system.

Potential cost of such a solution begins from 1000 PLN and includes purchase of programmer environment and software. The upper limit is impossible to define as it depends on the number of data and time of safekeeping. Usefulness of the system depends on many factors like i. a. reliability, number of stored data and performance, while these depend on borne costs. Nowadays system operates optimally in relation to the outlay. However, in future this paid solution would be more safe and reliable.

Solutions presented in the following study are interesting for telecommunications companies as the incidence of diabetes is still growing.

Similar system has been tested with positive results by the Orange Austria mobile network operator, Pilinger [14]. There are essential differences when comparing the above-described system with the solutions within Orange Austria.

Orange Austria service only monitors the patient.

The service operates only with Accu-Check Combo System based on the Bluetooth technology.

System described in the following study is not only based on monitoring the patient, but also thanks to the neuron wavelet algorithm it predicts the necessary insulin infusion. As soon as the system includes pharmacodynamics parameters of insulin drugs, it would be possible to define the dosage by the insulin pump.

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