Virtual Tools for Fast Registration, Processing and Presentation of Biomedical Signals in “Multimag” Complex

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***Abstract* — The article covers structural realizations of hardware and software parts of virtual tools of fast registration, processing and presentation of biomedical signals in “Multimag” complex. Methods for recording cardiac and respiratory rhythms, main properties of heart rate variability and diagnostic indices are shown.**

***Keywords* — biofeedback, chronomagnetotherapy, photoplethysmogram, pulsogram, rhythmogram, histogram, ultrasound echolocation.**

I. Introduction

The system of complex magnetotherapy of “Multimag” family is a hardware-software complex, which allows to create an almost infinite number of different configurations of the magnetic field affecting a patient. A certain configuration of the magnetic field (a method of treatment) is formed by a control program on a computer included in the complex.

The usage of biotechnical feedback sensors in complex magnetotherapy systems is helpful primarily for patient's functional state diagnostics, for controlling dynamics of his state change during a session, and for correcting the therapeutic effect depending on received diagnostic information of a patient. This correction, which determines changes in frequency-time parameters of the magnetic field (MF) in accordance with patient's recorded biorhythms, significantly increases the effectiveness of the therapeutic effect called chronomagnetotherapy [1]. On the other hand, the correction of the influence can occur in terms of fast change of the effect intensity over time during the corresponding dynamics of a patient's state.

The functional state of a patient's body has a tonic component – basic level of activity of main physiological systems and physical components that are formed when it is necessary to implement certain types of activities. One of the most common methods for controlling the functional state of the body is heart rate variability (HRV) analysis, which has been widely used in clinical practice and applied physiology [2].

Thus, biotechnical feedback sensors of a patient allow to promptly analyze the functional state of the organism, to signal and disable MF in case of patient’s state worsening during the session, to increase the effectiveness of treatment due to adjustment of the influence parameters and its synchronization with patient's biorhythms [3].

II. Registration of Biomedical Signals

To obtain diagnostic information about patient’s condition, “Multimag” complex implements virtual diagnostic devices that are software-controlled data collection systems in which simulation models of real or hypothetical diagnostic devices are organized. Moreover, not only control tools and displaying tools are software, but also the device’s operation logic. Communication between the program and technical means of biomedical signals registration is carried out through the interface nodes, which are drivers of external devices.

Hardware implementation of the biomedical signal recording channel can be represented as a generalized structure (fig. 1).

S – the sensor is a structurally separated converter of the recorded physical quantity into an electrical signal.

MT – the measuring transducer performs a number of analog and digital transformations of the signal, and as a result forms a sequence of coded signal values.

MC – the microcontroller registers a digital measuring signal, processes it and sends it to PC.

I – the interface is a hardware-software unit which provides communication between MT and PC.

PC – the personal computer registers biomedical signals from different measuring channels, processes them, accumulates them and presents them to the operator in a convenient form.

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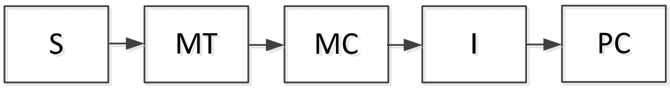

Figure 1. General structure of the hardware implementation of the biomedical signal recording channel

Registration of biotaxis parameters is carried out during the whole session of magnetotherapy. The methods and means used for this purpose should provide technical possibility of collecting biotechnical information to determine desired parameters under conditions of the magnetic field and, at the same time, they should create comfortable conditions for the patient and staff.

Biomedical signal sensors in most cases should be fixed on the patient's body during the session. However, to improve convenience of using the complex, it is better to consider contactless methods of collecting biomedical signals, as a result of which there is no inconvenience to the patient, and electrical safety requirements for the magnetotherapeutic complex are reduced due to the absence of direct contact with the patient's body.

The measuring signal from the sensor’s output is transformed according to the type of biomedical signal being registered and according to the method used in the recorder. The main biomedical signal transformations are amplification, demodulation, filtering, scaling, analog-to-digital conversion, etc.

Then digitized biomedical signal is registered by the microcontroller. The main task of the microcontroller is to translate the signal into the control program on PC. In addition to physical implementation of the communication channel, it is necessary to ensure compatibility of data formats on transmitting and receiving sides. This is organized by data transfer protocol. In order to do this, the signal is “packed” according to the specified data transfer protocol and transmitted to the data transfer interface. In addition, the microcontroller can perform digital signal processing and calculate required diagnostic parameters, as well as transfer them through the interface to the PC. The basic requirements are that the microcontroller must have sufficient hardware resources for recording, processing and transmitting this biomedical signal with specified metrological characteristics.

Currently, there is a group of standards which describes the interaction between personal medical devices and computer systems, defines a set of information objects and functions which are necessary to obtain data on basic indicators of body state from personal medical devices and management of these devices [4]. ISO/IEEE 11073 standard describes an objects interaction protocol irrelevant to physical implementation of the communication channel. It allows to implement the interaction between medical devices connected via wired or wireless channel.

When choosing an interface between the microcontroller and the PC, one should consider if it is supported by the hardware on both sides, provides required data transfer speed and stability of the data transmission channel in operating conditions of the magnetotherapeutic complex. For connecting to PC, USB2.0 is the most common interface, it allows to build a virtual COM port to connect most universal microcontrollers.

Transition to wireless transfer of data gathered from sensors has obvious advantages, because it eliminates wires “entangling” the patient and the diagnostic examination is becoming faster and more comfortable for both the patient and medical staff conducting the examination with this device.

For software implementation of an appropriate communication channel within ISO/IEEE 11073 standard, corresponding communication channel drivers are necessary. For different implementations, these drivers are developed at the level of communication channel profiles. The profiles are general mechanisms (protocols and functions) through which available devices interact with other devices within the communication channel.

For Bluetooth connection between medical portable devices within ISO/IEEE 11073 standard, HDP (Health device profile) profile was developed. HDP is designed to regulate and control the interaction between various medical devices and sensors via Bluetooth. To develop this profile, the world's leading manufacturers of Bluetooth equipment have formed an international Medical Device Working Group. The main purpose of this organization was development and creation of a Bluetooth profile which allows to interconnect medical sensors and medical measuring devices of different manufacturers. As a result, two main normative documents were created and approved in 2008: Multichannel Adaptation Protocol (MCAP) and Bluetooth Health Device Profile (HDP). In 2009 they were accepted for implementation by the majority of the world's leading manufacturers of Bluetooth equipment [5].

There are also other technologies for wireless transmission of medical data. Thus, in 2009, ZigBee alliance – the developer of ZigBee technology, suitable for building wireless networking solutions – announced the completion of a medical device profile (ZigBee Health Care public application profile). The new ZigBee profile establishes a global standard for data exchange between wireless devices from different manufacturers for safe and reliable monitoring of non-critical medical parameters [6]. It provides full support of IEEE 11073 devices, including glucometers, heart rate meters, electrocardiographs, medical scales, thermometers, blood pressure monitors and breathing parameters meters.

III. Biomedical Signal Registration Channel Software

Software implementation of the channel for recording, processing and presentation of biomedical signals in a control program can be represented as the following generalized structure (fig. 2).

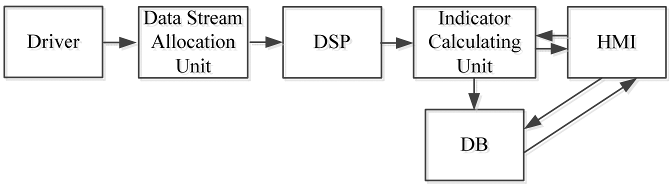

Figure 2. General structure of the software implementation of the biomedical signal recording channel

The driver is the program part of the interface for registering input data.

The data stream allocation unit generates a measurement data stream from input data (bytes) according to the transmission protocol.

DSP – digital signal processing, where all necessary transformations of the measuring signal are carried out. As in the hardware part of the channel, the main transformations are: amplification, filtering, detection, integration, differentiation, etc.

The indicator calculating unit – carries out allocation and evaluation of required diagnostic parameters and properties of the measuring signal.

DB – the database of accumulated diagnostic data. With general transition of modern clinics to electronic medical patient records supporting cloud storage of medical information, there is a clear tendency of saving accumulated diagnostic data for a given biomedical signal recording channel into a single patient database in the clinic.

HMI – the human-machine interface, which implements presentation of diagnostic biomedical patient data under control of an operator.

IV. BIOTECHNICAL FEEDBACK CHANNEL OF “MULTIMAG” COMPLEX

To solve the task of creating biotechnical feedback within complex chronomagnetotherapy “Multimag” device, there is a number of measuring tools aimed to determine specific physiological parameters of a person for their further analysis and processing. At the same time, magnetotherapeutic technique and intensity must adapt to instantaneous and trend values of these physiological indices. The first regulation circuit, which implements the mechanism of bio-adaptation, is synchronization of magnetotherapeutic effects with human biorhythms. The main physiological indicators, which can determine the overall functional state of a person and are convenient for registration, are cardiac and respiratory rhythms. Therefore, during the magnetotherapy session, “Multimag” complex determines patient's pulse and respiratory rhythm, which allow to diagnose patient's condition and to implement the influence adaptation mechanism.

V. REGISTRATION AND ANALYSIS OF PULSE INDICATORS

Today there is a large number of cardiac monitoring tools, numerous families of electrocardiographs, rheographs, photoplethysmographs, tomographs, etc. However, considering features of chronomagnetotherapy associated with a significant level of dynamic electromagnetic field around the patient, photoplethysmography is relatively acceptable in terms of noise resistivity. It is enough to fix a pulse wave sensor on a patient’s finger. In addition, most of these sensors, besides controlling the pulse, can simultaneously control oxygen saturation of blood.

Pulse oximetry is the most accessible method of fast monitoring of patient condition in many cases. It allows to calculate oxygen saturation of arterial hemoglobin and pulse frequency and thus to evaluate the efficiency of heart and lungs, to diagnose various hypoxic conditions.

The pulse signal is recorded photometrically by measuring the intensity of infrared radiation transmitted through the patient’s distal phalange. This value depends on the optical permeability of finger tissues, which changes when blood vessels filling changes during the pulse cycle. The output signal of the photometric sensor is an electrical signal called pulsogram.

An informative parameter in the recorded signal is oscillation periods, which are defined as time intervals between certain characteristic points of the signal. It is convenient to use the maximum value of a signal during a period – systolic maximum. However, because of the small amplitude of oscillations compared to the constant component of the signal, as well as many artifacts affecting signal recording conditions, there are certain difficulties in determining the moments of the signal maximum, especially if it is necessary to do this in real time. Some special methods should be considered for detecting the signal.

To register the pulse, “Multimag” complex includes a “Contec” photometric pulse oximeter. This sensor registers the pulsogram and determines pulse rate and oxygen saturation of arterial hemoglobin. The sensor contains a built-in microcontroller which processes the recorded pulsogram and determines heart rate and saturation. Information from the sensor is transmitted to the control program on PC via USB interface, the data packet format is described in the specification for this sensor. Each packet consists of 5 data bytes and contains pulse values, saturation, pulse signal counts, status flags and synchronization bits. Packing frequency is 60 Hz. Thus, at this stage the pulse signal is not processed – instantaneous pulse values determined by the sensor’s controller are used instead.

A sequence of pulse values forms a rhythmogram, which is used for determining the characteristics of heart rate variability (HRV). These characteristics are divided into graphic and spectral characteristics in the time domain [2].

Time domain characteristics include:

1) *mRR* – average duration of cardiointervals (CI) during the observation period, integrally characterizing the level of circulatory system functioning, expressed in ms.

2) *SDNN* – standard deviation (expressed in ms) of CI values for the entire reviewed period, estimates total power and reflects all cyclic fluctuations in HRV structure.

3) *RMSSD* – square root of the mean square of the differences between the values of consecutive CIs of the analyzed time series, indicates activity of the parasympathetic link of vegetative regulation.

4) $NN50$ – number of pairs of consecutive CIs which differ by more than 50 ms, obtained for the entire recording period.

5) $pNN50$ – percentage of *NN50* to the total number of consecutive CIs received for the entire recording period (expressed in %).

6) *CVr* – variation coefficient, which is a normalized estimate of the variance (expressed in %).

7) ΔX ($MxDMn$) – variation range equal to the difference between extreme (largest and smallest) values of the attribute in a given set, expresses the range of neurohumoral regulation influences.

8) *Mo* – mode, CI value most often encountered in a given sample (expressed in ms).

9) *AMo* – the fraction of CI durations values corresponding to the mode value to the total number of CIs (expressed in %).

10) Index of vegetative balance (IVB) indicates the ratio between the activity of sympathetic and parasympathetic parts of autonomic nervous system (ANS).

11) Regulatory processes adequacy index (RPAI) reflects correspondence between the activity of the sympathetic division of ANS and the leading level of sinus node functioning. This indicator allows, by comparison with the pulse rate, to judge whether there is excessive or insufficient centralization of cardiac rhythm control. An increase in IVB and RPAI values reflects activation of the sympathetic division of ANS, its predominance over the parasympathetic one, that is a nonspecific adaptive mechanism under the stress of various etiologies.

12) Tension index (TI). Informs about the tension of compensatory resources of the body, reflects the functioning level of the central contour of heart rhythm regulation and characterizes the initial vegetative tonus.

13) Vegetative rhythm index (VRI). Reflects activity of the autonomous circuit of heart rate regulation, calculated mathematically.

HRV graphic methods, defined during the operation of “Multimag” control program:

1) Rhythmogram – variation of cardiac contraction period over time.

2) Histogram of CI probability distribution (variation curve).

3) Scatterogram (correlation rhythmogram). Representation of consecutive pairs of CI (triples – previous, current and subsequent) in a two-dimensional (or three-dimensional) coordinate plane. The current CI value is plotted along the absciss and the next CI value is plotted along the ordinate. The area of points on the scatterogram is called Poincaré or Lorentz spots.

“Multimag” control program interface displays characteristics recorded from the pulse oximeter sensor during the magnetotherapy session: oxygen saturation (in %) of blood, pulse rhythmogram, initial pulsogram, HRV characteristics in the time domain, and graphical HRV characteristics.

VI. Control of Patient Respiratory Parameters with Complex Chronomagnetic Therapy

As the first stage of creating a device for complex physiological state diagnostics by patient’s respiratory rhythms, a non-contact ultrasonic respiratory sensor was integrated into “Multimag” complex. The developed sensor contains both hardware and software parts and allows to record parameters of patient’s breathing during the session of complex magnetotherapy, as well as to identify phases of inhalation/expiration. The principle of recording the respiratory rhythm is based on periodic measurement of the distance to patient’s thorax in the process of breathing.

Structurally, the breathing sensor is located in the upper segment of “Multimag” inductors in such a way that when the upper segment is installed above the patient, the transmitting and receiving transducers face the central part of patient's thorax.

The principle of the sensor is based on ultrasonic echolocation. Two different ultrasonic transducers built into US-100 or similar ultrasonic unit are used for radiation and ultrasound reception.

The principle of registering the respiratory rhythm is based on periodic measurement of the arriving time of the ultrasonic echo of the signal after its emission because this value will vary depending on the location of patient’s thorax in the process of breathing.

Informative parameters in the recorded signal are temporal characteristics, such as: period (frequency) of respiration, duration of inhalation and exhalation phases, starting moments of inhalation and expiration phases. These characteristics are used for patient’s condition diagnostics during the magnetotherapy session, as well as for synchronizing magnetic effects with respiratory phases in terms of bio-adaptive regulation.

Next, the duration of each phase is determined by the time difference between the beginning and the end of a current phase. Based on the results of digital processing, the rhythmogram of breathing showing the duration of inhalation and expiration phases is constructed.

VII. Conclusion

Virtual tools for patient functional state diagnostics during the magnetotherapy session allow to gather received diagnostic information into a single program. In this case, information from different sensors can be presented in one program interface, stored in a single database, used together in decision-making algorithms for bio-adaptive regulation of magnetic effects.

The methods considered above implement the task of obtaining diagnostic information about characteristics of heart and respiratory rhythms. This information accumulates during the magnetotherapy session and allows to study changes in patient's condition. When taking the possibility of saving the accumulated data from session to session, it becomes possible to evaluate the effectiveness of treatment course as a whole.

In order to implement the effective synchronization of magnetotherapeutic effects with patient's biorhythms, device-patient models are being developed and studied.

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Using a Tableau Method for Checking the Database Logical Structure Correctness

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Abstract– **The paper has considered the issue of checking the database logical structure correctness. At the present, there are several methods for solving this issue in the world, but to test existing databases with different complexity in the structures, it is used a method based on the new algorithm using a tableau. This algorithm uses the chase method to check the join- and functional dependencies of the databases. The assessment of algorithm time complexity and convergence are presented in the next part. The last part of this paper, we try to illustrate an example by using this algorithm.**

Keywords- database, algorithm, logical structure, tableau, the chase method.

I. INTRODUCTION

The purpose of the algorithm is to achieve a successful checking of the right representability of relations out of constraint set ***C*** with its projections on the relation schemes of some database ***R***.

At the present time, within the limits of relational approaches in the theory of relational databases, there is a pressing issue of the correctness checking of schemes' logical structure. A properly structured database has the following advantages:

- High request processing speed;
- Smaller amount of taken memory;
- Proper functioning;
- Lack of redundancy;
- Comprehensibility and certainty.

The task of the correctness checking of the logical structure is still open.

II. THEORETICAL RESEARCH

At the present time, there are several options for tracking the correctness of constructing the databases[1,2]. For example, when designing the base from scratch different systems of database management allow monitoring the structures online. Their disadvantage is that it is impossible to analyze finished databases[3]. There are some automated systems which allow getting the information about the structure of such bases. Usually, as the result of these software solutions the user gets the information in the ER-chart form and after that, he needs to analytically check the correctness of the structure. In cases of difficult databases, this task becomes intractable.

The checking of databases without using a tableau is also possible through its decomposition and search for losses. For the decomposition, it is necessary to have the full information about the scheme of the base, in particular, all the attributes and connections between them, and about existing dependencies. The processing is very labor-intensive due to the absence of structuring in data storage. It is particularly hard in the cases of dealing with big and difficult databases[4,5,6].

The tableau allows ignoring the content of the database. It gives the possibility to keep all the information in a visualized and convenient to handle format without using any extra data or parameters.

In order to check the database, it is also possible to use the method of representative samples. A representative sample is a sample out of the sampled population with the distribution *F(x)* representing the main features of the sampled population. The sample (empirical) distribution function $\hat{F}(x)$ subject to the large range of samples, provides a good enough indication of the sample distribution function *F(x)* of the original sampled population. However, this method is also rather labor-intensive and, just like the other statistical method, is relatively low reliable.

The developed algorithm of checking the logical structure of schemes is based on the usage of scheme decomposition and the application of tableau to detect date losses.

As a result of the performed algorithm, the answer to the question "Is the decomposition without the losses of relation out of constraint set ***C*** into ***R*** possible" will be given.

A tableau is a tabular procedure of representing *PJ*-reflections (reflections "projection-connection") [1,7,8,9].

A tableau reduction is a tableau that consists out of the set of all lines of the original tableau, and none of them is absorbed by the other lines [2,10,11,12].

The equivalence of two tableaux with the restrictions gives us the opportunity to check the cases when *PJ*-reflection does not have any losses in the constraint set.

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Two tableaux are equivalent when their reductions are the same to within the one-to-one renaming of not distinguished symbols [2].

The algorithm uses the method of the chase.

The method of chase is a computational method with the help of which for a given tableau *T* and the dependency set **C** a new tableau *T** is constructed, the kind that $T \equiv T^*$, and *T** as a relation belongs to SAT(**C**) which is a subset of database scheme set, satisfying ***C*** [3,14,15,16].

With the help of the chase, the tableau is tested for equivalence on ***C***.

In the terms of equivalency of a tableau, for the successful testing of discovering the dependencies in the connection the fulfillment of the condition $TR \equiv cTI$ is needed, where *TI* is the tableau consisting out of one line of distinguished variables. The letter c means the existence of a set with all kinds of constraints applicable to the tableau. The equivalency $T1 \equiv cT2$ is true if and only if

chase c(T1) ≡ chase c(T2),

i.e. if the final tableau *T1*, according to the method of the chase, is equivalent to the final tableau *T2*.

This means that it is enough for us when this condition is fulfilled

chase c(TR) ≡ chase c(TI).

But as far as *chase c(TI)=TI*, then

chase c(TR) ≡ TI

Therefore, the necessary and sufficient condition of the checking is the availability of the line of distinguished elements in *chase c(TR)* [17].

Similarly, for the successful testing of discovering the functional dependencies of $X \rightarrow Y$ kind the necessary and sufficient condition of the checking is the availability of only distinguished elements in the column, corresponding to the attribute *Y*, the final tableau according to the method of *chase c(TR)*.

We outline the method of checking.

Input data:

- database scheme ***R***;

- constraint set ***C***.

The general scheme of the algorithm can be seen in Figure 1.

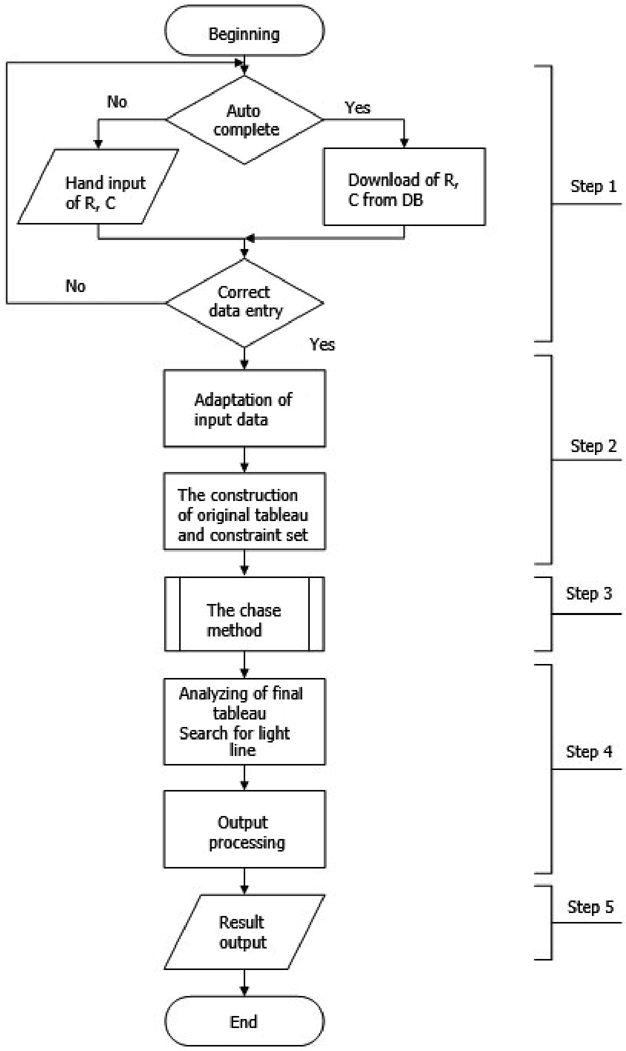

Figure 1 – The general scheme of the algorithm

Let us take a closer look at the performance of the algorithm step by step.

At the first step, there is a correct data entry: the scheme ***R*** and the constraint set ***C***, which is a population of *F*- and *J*-regulations (functional and join), there is the checking of the correctness of data entered.

At the second step of the algorithm the adaptation of input data is in progress, i.e. the data are transformed in a way it can be best processed, and the original tableau *TR* in the scheme ***R*** is constructed.

The third step is the performance of the chase method.

The method is as follows: *for the specified T and **C** F- and J-regulations are applied, corresponding to F- and J-regulations out of **C** until they cause changes*.

At the fourth step, there is an assessment of equivalence. For the dependencies of the connection, the final tableau *T** is checked for the equivalence to *TI* (the tableau that consists out of the only line of distinguished elements). T^* is equivalent to *TI* if there is a line of distinguished elements in T^*. For the functional dependencies, there is a check only for distinguished elements in the corresponding column.

At the fifth step, the result output happens.

The chase method and the assessment are presented schematically in Figure 2.

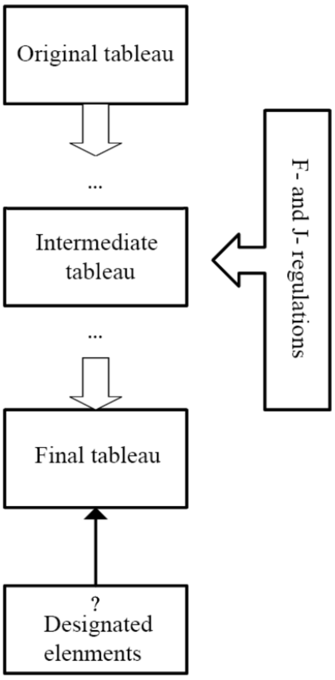

Figure 2 – The chase method and correctness checking

III. THE ASSESSMENT OF ALGORITHM TIME COMPLEXITY AND CONVERGENCE

The tableau is a set of lines, and none of the *F*- or *J*-regulations does not enter any new variables, there is only a finite number of tableaux which can appear in a generating sequence *T* relatively to ***C*** [18,19]. That is why the algorithm always converges.

Generally, the process of the chase method has an exponential time complexity [20]. If the tableau *T* has *k* columns and *m* lines, *chase c(T)* can have *m^k* lines. In the case of using the process of the chase method in order to check the nonexistence of information losses in the connection, the full procedure is not always needed. As soon as the line consisting only out of distinguished variables is gotten, there is no need for continuing the checking. If this line is a part of any tableau of generating the sequence, it will appear in the final tableau. However, the problem of identification of line of distinguished elements to *chase c(T)* probably does not have a polynomial-time decision because it is known that the problem of the checking of $C \models * [S]$ is NP-hard. For the checking of $C \models c$ other methods exist which, contrary to the chase method, have in case of *F*- or *J*-dependencies a polynomial time complexity.

By virtue of the fact that *F*-regulations does not induce any new lines, the process of chase method *chaseF (T)* for the set of *F*-dependencies *F* never has more lines than *T*. It is no wonder then that *chaseF (T)* can be calculated in a polynomial time. Let us suppose that the task inputs is the tableau *T* and the set *F*. For simplicity in what follows, we assume that every attribute or tableau variable takes one storage unit.

Suppose that $k = |U|$ = a number of *T* columns, m = a number of *T* lines, p = an amount of storage for the recording of *F*.

The amount of input is $n = O(k\text{-}t_n + p)$.

Let us show how to calculate *chase c(T)* in a time $O(n^3)$. We begin to make up rerunning on the set of *F*-dependencies. For every *F*-dependency $X \rightarrow A$ let us group together the lines with equal definitions of *X*-component. If $|X| = q$, the sorting takes $O(q\text{-}t_n)$ of time. After the sorting for $O(q\text{-}t_n)$ of time, we find the lines with equal definitions of *X*-component and identify their *A*-columns. The sum of the left parts amounts, according to all the *F*-dependencies out of *F*, does not exceed p. Therefore, one running through all the *F*-dependencies takes $O(p\text{-}m)$ of time.

We continue to make rerunning through *F* until the changes stop appearing in *T*. Let us stop at this. At the beginning, *T* can have no more than *k-m* different variables. Every rerunning, except for the last one, decreases the number of variables by one, thus, we have no more than $O(k\text{-}m)$ rerunning. The total time of the rerunning procedure is $O(k{*}p{*}\ m^2)f$ which does not exceed $O(n^3)$.

If the tableau complies with the database scheme, and there are only schemes put by as an input, the procedure described above takes $O(n^4)$ of time where *n* is the amount.

With a view to simplifying *F*-regulations, we have still assumed that all of our *F*-dependencies have one attribute on the right. *F*-regulation can be summarized in case of many attributes on the right side of *F*-dependency. If *w1* and *w2* are the lines in the tableau, such as $w1(X) = w2(X)$ and $X \rightarrow Y$, there is an *F*-dependency within the limitations, than it is possible for every *A* attribute, which is also a part of *Y*, to be identified to *w1 (A)* and *w2 (A)*.

There is also a generalization of *J*-regulation which allows us to generate more than one line at a time. If * *[S]* is a *J*-dependency out of constraint set, then it is possible to apply *PJ*-reflection of *ms* to the tableau and the result can be used for the making of the next tableau in a generating sequence.

IV. AN EXAMPLE OF ALGORITHM'S WORK

Let us consider the database scheme ***R***={*AB*, *BC*, *AD*} as an example. Let the constraint set be ***C***=($A \rightarrow D$, *[*AB*, *BCD*]). We apply the worked out the algorithm in order to get the final tableau. Original T1 and final T1* tableaux are presented in Figure 3.

T1

A	B	C	D
a1	a2	b1	b2
b3	a2	a3	b4
a1	b5	b6	a4

T1*

A	B	C	D
a1	a2	b1	a4
b3	a2	a3	a4
a1	b5	b6	a4
a1	a2	a3	a4
b3	a2	b1	a4

Figure 3 – The original and the final tableaux for R, C

Given that *chase c(T1)* contains the line of distinguished elements, then any relation from *SAT(C)* without any losses decomposes into ***R***.

For the database scheme *S*={*AB, DC, CD*} *chase c(T2)*, found by the worked-out algorithm, does not contain the line of distinguished elements. In *SAT(C)* such relations exist which have losses while decomposing into *S*. The original T2 and the final T2* tableaux are presented in Figure 4.

T2

A	B	C	D
a1	a2	b1	b2
b3	a2	a3	b4
b5	b6	a3	a4

T2*

A	B	C	D
a1	a2	b1	b2
b3	a2	a3	b2
b5	b6	a3	a4
a1	a2	a3	b2
b3	a2	b1	b2

Figure 4 – The original and the final tableaux for S, C

V. Conclusion

The worked-out algorithm which uses the tableau gives the opportunity to analyze the correctness of logical structure of the databases made from scratch or already existing. In case of further improving the algorithm, there is an aim to add the checking given multivalued dependencies and the possibility to check database structure with the attributes of varying degrees of protection.

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Double Interpolation in GIS Tasks

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Abstract— **In this paper considers the development of a project module "Mobile GIS", providing the possibility of building surfaces and contours on the basis of a set of information about the altitude in certain points. The variants of the acceleration of the operation of the double interpolation algorithm for the processing of heterogeneously distributed data are considered. The application of various interpolation functions of two variables is considered and the quality of recovery of the result is analyzed.**

Keywords-component; GIS; Interpolation; Approximation; Point cloud; Maps

I. INTRODUCTION

When composing thematic maps, one often has to deal with the problem of comparing to a point cloud A_n of a function $z = F_A(x, y)$. Point cloud is a set of data obtained in the course of measuring works, represented as a three-dimensional point $A_i = (x_i\ y_i\ z_i)$, where x_i and y_i – are the coordinates in which the measurement is obtained, z_i – is the numerical value of the measured parameter. In most cases, we can say that the function is piecewise and can hardly be described mathematically for an adequate time.

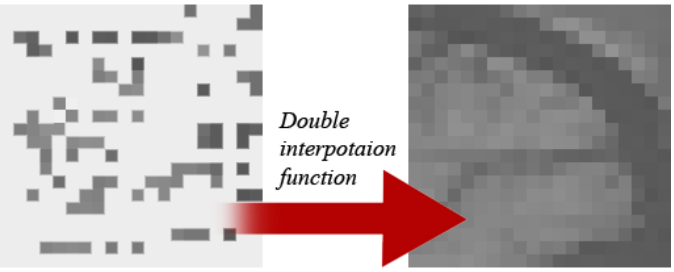

Figure 1. Task of double interpolation.

In this case, the optimal solution is to find not the function itself, but the set of values required for analysis. The method of finding intermediate values of a quantity from the available discrete set of known values is usually called interpolation [1]. Double interpolation is a subset of the interpolation problem, where the value of the intermediate value is calculated for a function of two variables. In the future, this article is about this.

Double interpolation can be used to obtain a set of values of any parameters (weather data, geological structure of the soil, etc.). Of this article, we will talk about finding heights based on LiDAR survey, barometric measurements and SRTM data [2].

II. GRID STEP AND REGION SIZE

Before proceeding with the construction of matrices, it is necessary to select the regions and the grid step, indicating the degree of detail of the data obtained.

The grid spacing is selected in such a way as to provide maximum informative value, while avoiding the calculation of an excessive number of values. The boundaries of the value calculation area are selected in such a way that sufficient data is available near the points to calculate an adequate value.

The selection of interpolation region boundaries should be approached very attentively. If it is chosen too small, then not all places on the map will be able to calculate the values. If it is too large, then they will have a very low degree of adequacy.

In the course of the experiment, the following dependence of the SD on the distance to the nearest points in which it is possible to calculate the value was found. It should be noted that the SD values are very conditional, and depend on the behavior of the function on the plane. However, the general form of the dependence corresponds to the following figure:

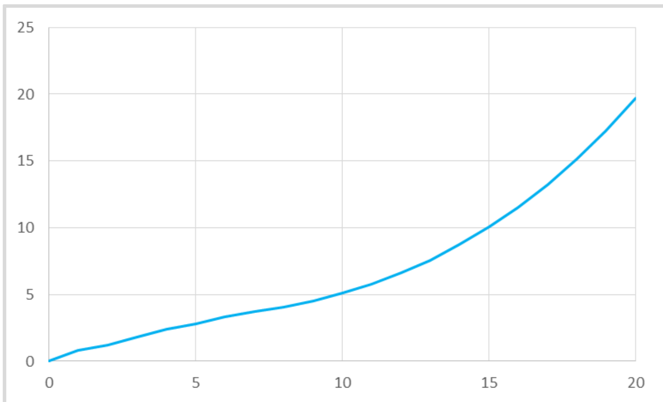

Figure 2. SD dependence on distance to pixel.

III. NEAREST POINTS SEARCH ALGORITHMS

Based on double interpolation for each point of the matrix of heights, the value is calculated as follows:

1. For the selected point, there are n-nearest values.

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2. Filtering and sorting based on the selected values.
3. The interpolation function is applied to the remaining values.

The selection of the nearest values to a point can be based on the search of all existing points. However, the use of this option is inexpedient, because when working with a large number of points the processing time multiplies [3]. As a solution to this problem, two variants of searching for neighboring values were considered.

A. Spiral search

If all the existing values already represent nodes in the final matrix, then a variant of spiral search is allowed. The search algorithm is as follows:

- For a selected point, the neighborhood of 3x3 is analyzed for the presence of initial values in them.
- In the case that a sufficient number of values is collected, the algorithm stops its work, otherwise the next neighborhood is analyzed – 5x5, and excluding the neighborhood 3x3 from it (it turns around the perimeter of the square).
- This algorithm is executed until a sufficient number of points n is collected, or the boundary of the search area is reached.

This algorithm allows an average of 100 times faster to find neighboring values in the matrix, but it is only applicable if the coordinates of the initial cloud of points are discrete and already represent nodes of the finite matrix.

B. Search based on square-divisioning

This option is one of the ways of indexing values in the matrix. The assignment of the index to the square is performed in the same way as in Figure 3.

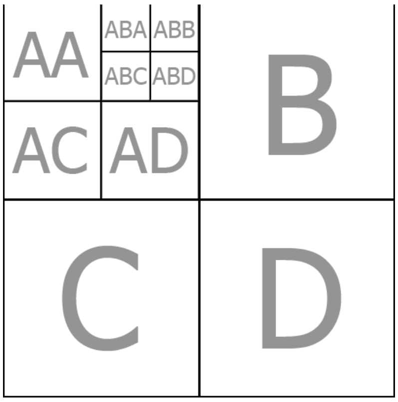

Figure 3. Split the matrix into squares.

The whole image area is divided into 4 squares conventionally called A, B, C and D. We will assume that all points with coordinates x smaller than the center of the image and the coordinates of y smaller than the center of the image belong to the square A. Similarly for B, C, D. For each square, the index in the sub-square is defined.

For each element from the cloud of points, its index is based on the location of the point. For example, for the point located in the upper right corner, the "AAAA" index will be assigned. The degree of fragmentation of the matrix (the number of letters) is chosen in such a way that each square has an average of no more than 10 points. This partitioning makes it possible to find the neighboring elements most effectively.

It should be noted that the use of this method, unlike the previous one, allows storing the coordinates of a cloud of points not only in integers but also in fractional coordinates. In addition, in matrices with a very rare arrangement of elements, this method significantly improves the performance in comparison with the previous algorithm.

In case, you need to find neighboring elements, the values in the current square are analyzed. If the distances to these elements are greater than to the boundary of the square, then adjoining squares are connected to the analysis, and so on, until a sufficient number of values are collected.

To store data, the Dictionary class is used, in which the index is a string parameter, the point coordinate according to the principle described above, and the index value is a set of points corresponding to a given square [4]. There can be several points in the square, and not even one.

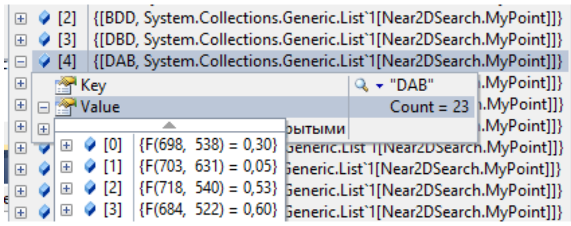

Figure 4. A dictionary with squares, and the first 3 points for a square "DAB".

IV. Double Interpolation Formula

When solving the problem of constructing a matrix of values from a cloud of points, the choice of the distance function is an important factor. It establishes a relationship between the intensity of the color and the distance to the pixel:

$$W = \sum_{i=0}^{n} w_i * F_l(l_i) \,/\, \sum_{i=0}^{n} F_l(l_i).$$

Here w_i – color value in the point, l_i – the distance from the determined point to the i point, $F(l_i)$ – the distance function, n – count of used points (n nearest points).

The form of the distance function was selected manually based on the change in the SD in various cases. The most reliable function is $F_l(l) = l^{-4}$. It should be noted that for these data (Weather maps, maps of deposits, etc.), the function may be different.

V. QUALITY CONTROL

In order to evaluate the algorithm efficiency, a series of SRTM images was selected. Some number of pixels (in %) was removed from the images, after which they were executed by the algorithm of double interpolation. The resulting image was compared to the original one based on the SD characteristic.

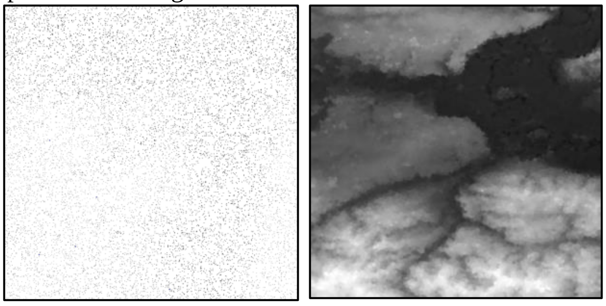

Figure 5. Recovered image from 5% of pixels. Used double interpolation. SD = 6.2.

In order to test the ability to interpolate both with a negligibly small amount of data, and at a high, the following values were chosen: 0.01; 0.1; 0.5; 1; 2; 5; 20; 50; 75; 90; 99. For each of them, 1000 experiments were performed on different sets of images. The following results were obtained:

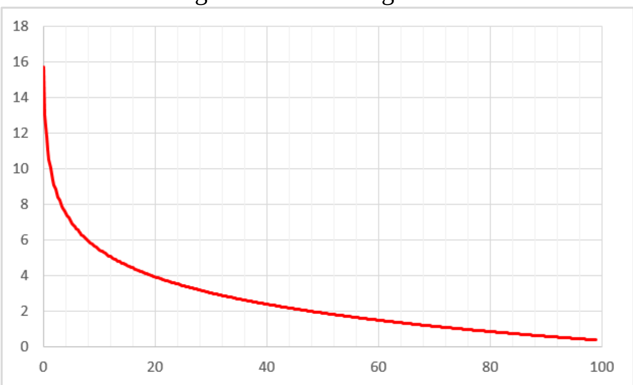

Figure 6. SD dependence on number of pixels (in %).

It should be noted that the result depends on the number of selected points for analysis. Too small a quantity will result in the values being too rough, too - to the fact that the result will be very blurred, and many times will increase the calculation time.

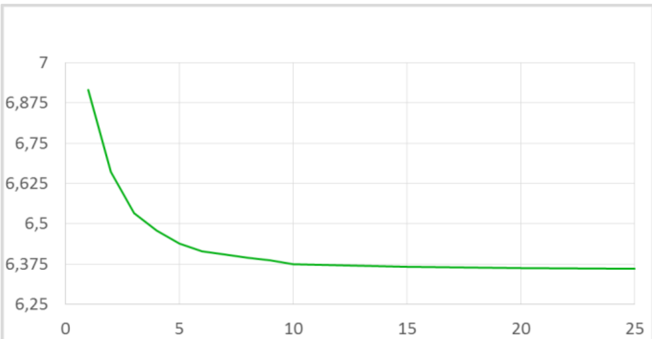

Figure 7. SD dependence on n (number of selected points).

VI. USE IN OTHER AREAS

In addition to GIS tasks, this algorithm can be successfully used in data compression and recovery tasks.

A. Recovering of damaged image

For example, in case of damage to m percent of points on the sensor, this algorithm will allow getting an image close to an adequate one, even though the losses are significant.

Figure 8a – Original Image. Figure 8b – recovered image from 20% of original data (1.6 bits per pixel, SD = 6.2).

B. Image compression

The double interpolation algorithm can be applied to image compression problems. For example, if you save 5% of the pixels from the image, and then transfer them through the channel, the picture size is reduced by 20 times in compared to the original image [5]. When it is restored to the final device, it is possible to achieve high accuracy. It has been experimentally established that such a recovery algorithm gives 30% better results than orthogonal transformation based on Walsh function:

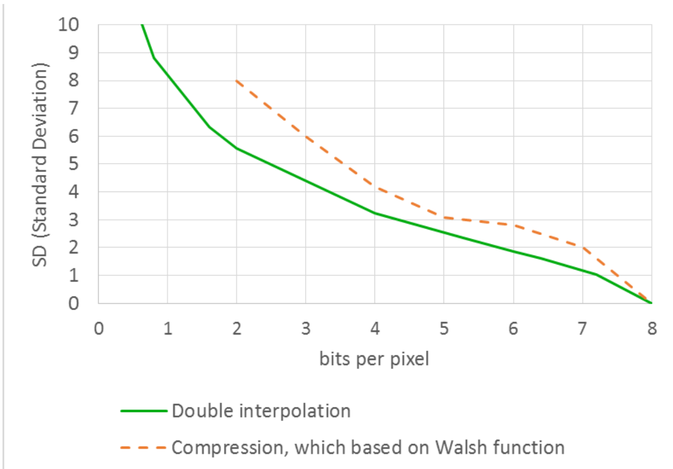

Figure 9. SD dependence of bits per pixel.

VII. CONCLUSION

As it was demonstrated in the article, the application of double interpolation algorithms can help in solving problems of finding values, as well as in image compression and reconstruction problems. The results obtained indicate low error rates. The use of algorithms for finding the closest elements and distance functions made it possible to significantly shorten the time of obtaining the result and improve its accuracy.

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Reliable IoT Systems for Improving Quality Of Life Through The Exploitation of Cloud, Mobile and BLE Based Technologies Case Study: SunProtect UV

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Abstract— **This paper presents the integration of mobile, cloud and embedded device communications based on existing internet infrastructure. Connecting various smart objects within an intelligent ecosystem provides high capability. Moreover the trend of Internet of Things (IoT), addressing health, quality of life, smart cities etc. has been presented.**

We described similar aspects with a proper case study (Sun Protect UV), relying on Nordic Semiconductors in which a health related mobile cloud application interconnected with a wearable device are presented. The research undertaken shall represent not just the technological innovation, exploiting state of the art technology, but also the health benefits related to this smart system.

Keywords. Internet-of-Things; IoT; Smart Devices; Fall detection; Energy eﬃciency; Wearable devices; Sun UV

I. INTRODUCTION

Internet of Things (IoT) concept and paradigm brings together existing internet infrastructure with everyday embedded devices such as smartphones or other microcontrollers in a common playground to improve people everyday life and provide smart innovative services.

Information technology relying on Internet has widely grown during the past decades. Thus all services and information are exchanged on World Wide Web (www). However a new concept arises with the need to provide interconnection not just between web browsers and cloud based servers / clusters with robust ISO protocols, but also between smart embedded devices.

The latter might rely on independent protocols with respect to the ones used for interconnecting Web applications. The main goal of the IoT is to bring together both paradigms of the 21st Century to collaborate in creating larger grids of intelligent services and devices.

Thus a mobile / cloud / embedded device interconnection through existing state of the art technologies shall be presented along this paper work. A development approach and methodology will be described and adopted to real case study addressing primarily health related issues.

Thus a system monitoring the UV through a mobile application and BLE device is unfolded in the coming section. The main purpose of the SunProtect Application is to control, predict and suggest the best UV dosage for its users, providing not just useful tips but also health benefits.

After results have been gatheredin the last section outcomes and challenges related to technological restrictions and decisions undertaken will be evaluated together with future proposals of improving existing approaches.

II. BACKGROUND

World Wide Web services are obviously the primary source and model of interconnection between services and information. Several existing embedded devices can become part, interact or controlled from existing web technologies. This would result into a combination between the previous two thus deriving the concept of Physical Web = Web Technology + IoT. [2]. Figure 1 represents an overview of the possible physical web architecture to be adopted.

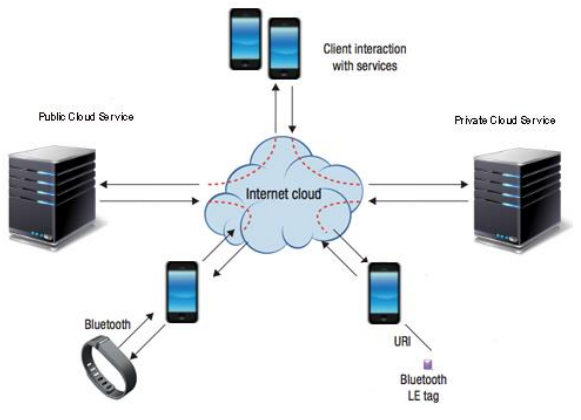

Fig. 1. Possible Architecture adopted to interconnect the existing cloud infrastructure with embedded devices relying on Bluetooth Low Energy (BLE) communication protocol

Existing concepts in web/cloud protocols will be extensively exploited along having a stable and robust infrastructure in storing data, sharing/retrieving information as well as guaranteeing high availability and scalability. Thus URI (Unique Resource Identifiers) and RESTful API (REST standing for Representational State Transfer) will be part of the system architectures.

Moreover further protocols are required in order to fill the communication gap between smartphones and embedded devices relying on state of the art microcontrollers.

One of the largely adopted technology is the one based on Nordic Semiconductors, which has a built-in BLE embedded inside its System on Chip (SoC) microcontrollers. Also the Bluetooth communication protocol relies on Generic Access Profile (GAP) and Generic Attribute Profile.

GAP covers the usage model of the lower-level radio protocols to define roles, procedures, and modes that allow devices to broadcast data, discover devices, establish connections, manage connections, and negotiate security levels, GAP is, in essence, the topmost control layer of BLE. This profile is mandatory for all BLE devices, and all must comply with it.

GATT deals with data exchange in BLE, GATT defines a basic data model and procedures to allow devices to discover, read, write, and push data elements between them. It is, in essence, the topmost data layer of BLE.

Both protocols assure a stable communication of data and services with SmartPhones having BLE technology built-in. (Integrated from Bluetooth vs. 4.0). This has result the most promising standard starting from 2010.

III. LITERATURE REVIEW

The paper addresses not just concerns related to technology but also the health benefits related to the exploitation of BLE embedded devices.

Many publications concerning UV (Ultraviolet) dosage intake have been a major concern related to skin health issues. One of the major risk being skin cancer.

While several articles during the past two years have been published related to development of embedded devices based on different microcontroller technologies. One of the most promising ones seems to be Nordic Semiconductors where BLE integration as a communication protocol has been made easy.

Several authors have presented the possibility of integrating into the Physical Web approach Cloud/Mobile and Embedded Devices, with high proficiency, security, availability and easiness of usage [7-9].

IV. METHODOLOGY

Development of an integrated environment of Cloud / Mobile and Embedded wearable devices consists in the following steps:

1. Development of the Wearable Device (Dongle)
2. Firmware Development providing the communication protocol between the mobile
3. Mobile App Development (Android / iOS)
4. Google Cloud Communication

The wearable device microcontroller is based on Nordic Semiconductor technology with nRF51 Development Kit, from which a firmware development in C programming language is made possible.

A Client / Server (C/S) Architecture is adopted for broadcasting services and exchanging data between the Mobile Application and the Wearable Device.

Firmware acts primarily as the Server while the mobile application developed in Android/iOS etc. shall act as a client communicating with the services offered from the server based on the GAP/GATT protocol.

Decision made from the mobile application shall also be based on communication with the Google Cloud Application. The overall architecture is described in Figure 2.

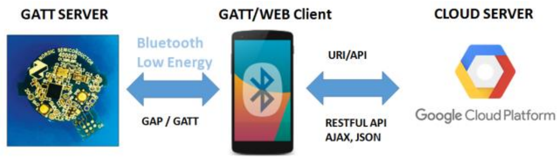

Fig. 2. IoT System Architecture

V. CASE STUDY

The chapter describes the actual implementation and development of the earlier described IoT Architecture. A developed wearable device has been implemented and shown in Figure 3 and 4, representing also the implemented service GATT table. The device is in charge of measuring sun UV. Alongside the wearable device a mobile application directly communicating with it has the capability of proposing suggestion for users best sun exposure throughout a day. The latter is providing the highest source of UVR for most people. However different skin types react differently towards solar radiations (UVR exposure) due to metabolic, genetic reasons or other types of skin abnormalities. Making long term exposure a health related issue not just due to sunburn but other more serious health concerns such as skin cancer (melanoma) or photosensitivity.

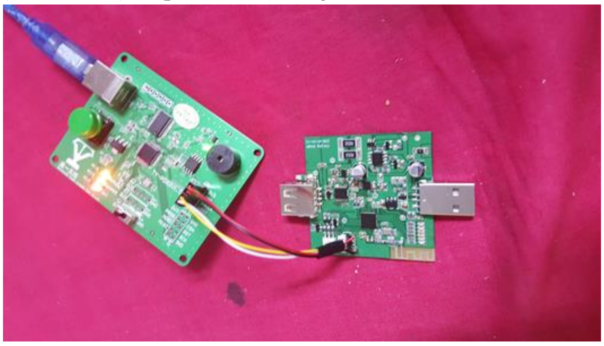

Fig. 3. Programming the device with Nordic Semiconductor Development Kit

Service	Handle	UUID	Permissions	Value	Length	Description
CG Service	0x0090	0x2800 - Primary service declaration	Read	0xC6C6 (Charge Guard)	2 bytes	Sunsense Service Description
Request Attr.	0x0091	0x2803 - Request Sun UV declaration	Read	0x0092	2 bytes	Request for Sun UV Factor
Charger value	0x0092	0x0111 - Set UV User Values	Read/Write	0x00 | 0x01	2 bytes	0x00 = OFF ; 0x01 = ON
Request Attr	0x0093	0x2803 - Voltage Characteristic declaration	Read	0x0094	2 bytes	Request for Data
Volt. target val.	0x0094	0x0112 - Set Skin Type	Read	0x00 | 0x01	2 bytes	Skin Health

Fig. 4. GATT service table

Since the background for such concerns is not at the knowledge of everyone, than it comes of good use to have an easy way to address this issue on daily basis. Benefits of Sun exposure such as vitamin D intake or immune system strengthening especially during childhood have been observed. But larger doses of exposure don't provide any further benefit. Thus a software system should be developed that controls and manages the maximum UVR exposure so the above mentioned health issues don't become a concern. It should monitor UV predictions and based on complex algorithms should provide estimates about sun exposure based on:

1. weather conditions
2. skin type
3. current skin tone
4. eye color etc.

If the health issues are not a concern the app can still be used for every day tips so that best sun exposure for best skin tanning, vitamin D intake etc. is guaranteed. The best portable system that can solve the problem nowadays would be a mobile application connected to device offering UV measurements. However a reliable data storage and sharing as well as computation of results has been implemented based on the Google Cloud Infrastructure.

Figure 5 and 6 represent the architecture of the developed mobile Application as well as the different implemented interfaces.

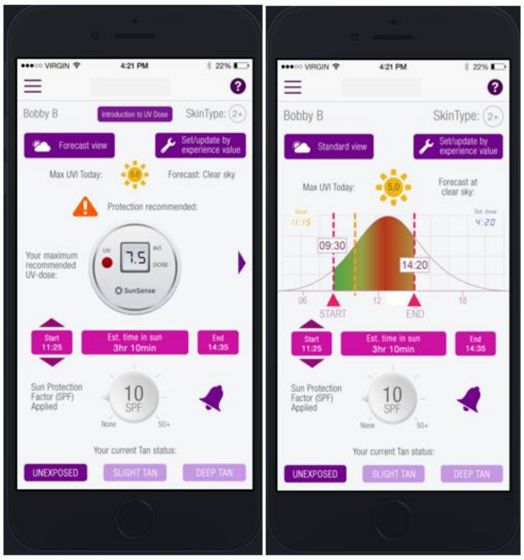

Fig. 4. SunProtectUV Mobile Application Architecture

While in Figure 5 is shown the Google Cloud Application architecture for storing/sharing and performing computations.

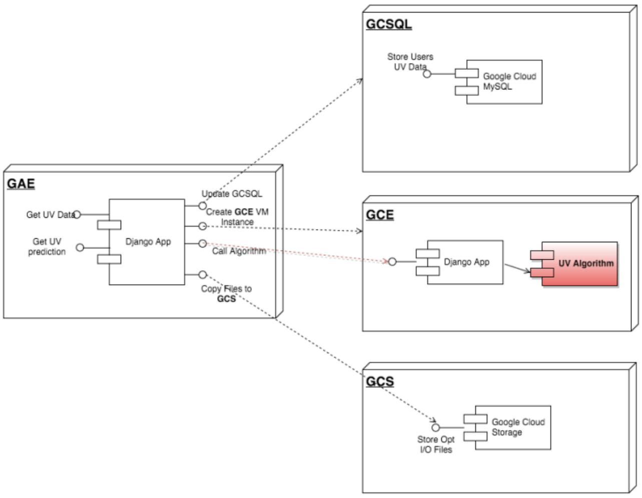

Fig. 5. Google Cloud Application architecture

The cloud infrastructure offers a reliable way of developing storing and sharing information for different users. It also offers more cost effective, and other benefits such as security or privacy, with little latency drawback. Thus providing the possibility of a personalized UV protection plan. The end user also has little or no knowledge at all about the system behind the scenes but it's offered a robust yet easy to use and comprehensive skin protection and health oriented service. And everything is estimated and based on high computation power offered from the cloud platform with very little computational power required from the wearable devices or smart phones.

VI. CONCLUSSIONS

In this paper we have shown the possibility of combining Cloud / Mobile / Wearable devices into IoT grid offering health benefits to the end users. The system can have two operational modes, online and offline, but also a well-structured synchronization logic.

Main benefits are related to easy to use, robust, reliable, secure and scalable system, yet with very little latency concerns.

However still practical issues remain to be addressed such as device proximity awareness, pairing and handshake protocols, centralized vs. peer to peer (p2p) approach, low latency and real time concerns and integration of devices with very low computational power.

A possible continuity could be evaluation of the systems on big scale and data analysis on long term basis.

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