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Modeling of Long Lasting Functional State of Healthiness Dynamics

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Introduction

The statistics claims, that people who are not physically active live shorter and they are ill more often. Human organism adaptation to physical load peculiarities and opportunities is an actual task of physiology, sports and clinical medicine. To choose the right activity the doctors have to investigate the patient, analyze and store his data for the future. The solution of this task is tight-knit to human functional state evaluation [1]. For correct specification of functional state, it is very important to integrate and evaluate main human organism systems reactions during physical load. For the evaluation of human functional state we used the model of integral health evaluation [1], which includes the main holistic systems [2]. For making decision about right and useful physical activity we analyzed the formalized effect model.

Modeling the long lasting functional state of healthiness dynamics we have to use the conception of both models. The final model should be variable, mathematically described and include the easy measurable clinical parameters. We proposed the model of convolution of Meally and Moore automata [3,4]. Wilfred Brauer described the automata, their types and behaviour. Recently Moore and Mealy automata have been very popular, but the studies on the conjunction of these automata are not numerous.

So the main purpose of this paper is to present the model of long lasting functional state dynamics using the method of automata convolution.

Description of the integral health evaluation model

We used the model of integral health evaluation (Fig. 1), that integrates changes of three functional elements: P – periphery system, R – regulation system (brain), S – supplying system (heart, blood-vessel system) [1,6].

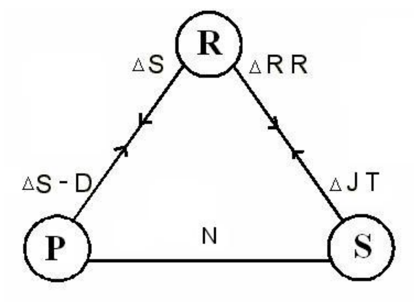

Fig. 1. The model of integral health evaluation

Relation between these systems can be specified by several parameters, but we used the simplest and easier calculated – RR interval (time between two beats of the heart), JT interval, systolic (S) and diastolic (D) blood pressure, and power, physical load in watts (N). All these parameters are taken from the standard stress test method of provocative incremental bicycle ergometry work by the ECG analysis system “Kaunas – Load” [1]. Let’s define the integral evaluation (Sv) [6]

$$Sv = \frac{1}{k}\sqrt{\Delta JT^2 + \Delta RR^2 + \Delta N^2} \cdot 100\%, \qquad (1)$$

here k is a constant, depending on patient gender [5], Δ is the difference between the parameter values at rest and at maximum power.

When estimating Sv, the functional state could be described in such a way:
$0\% < Sv \leq 40\%$ - a patient is at risk (pathology is suspected);
$40\% < Sv \leq 50\%$ - the threshold state;

50%<Sv≤70% - the functional state is normal;
70%<Sv≤80% - good, Sv>80% - perfect.

For the functional state dynamics during several tests we used the formalized effect model (See Fig. 2).

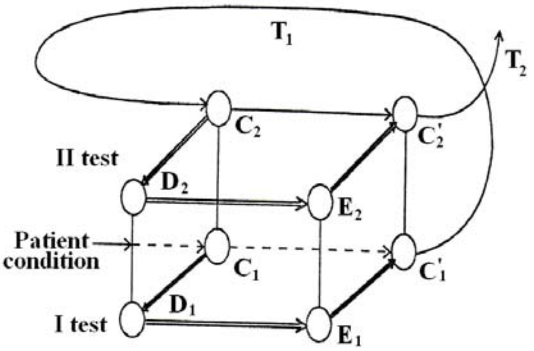

Fig. 2. The formalized effect model

The concept of this model is: patient comes to doctor, his condition is C_1, doctor tests him and makes a diagnosis D_1, selects the effect E_1 and forms the motivation – new condition C_1'. The effect time is T_1. After that time patient comes to the doctor, his condition is C_1, doctor tests him and makes a diagnosis D_2, selects the effect E_2 and forms the motivation – new condition C_2'. The effect time is T_2 and so on.

The description of Mealy and Moore automata convolution

Here we present how the integral health evaluation and formalized effect models described using the convolution of Moore and Mealy automata [3,4,5].

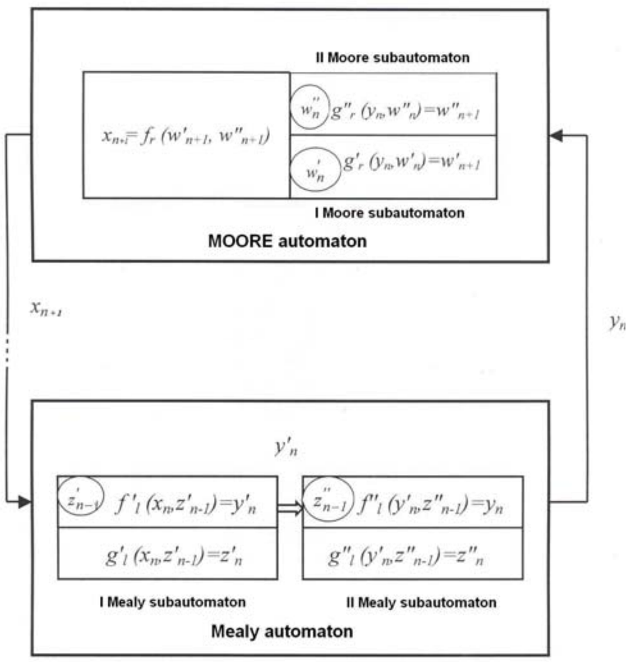

Fig. 3. The convolution of Moore and Mealy automata

The conjunction of Moore and Mealy automata (Fig.3) is called the convolution Mealy of and Moore automata. Surjections of Moore automaton:

$$\begin{cases} g'_r : W' \times Y \to W', \\ g''_r : W'' \times Y \to W, \\ f_r : W', W'' \to X. \end{cases} \quad (2)$$

Surjections of Mealy automaton:

$$\begin{cases} f'_l : X \times Z' \to Y', \\ f''_l : Y' \times Z'' \to Y, \\ g'_l : X \times Z' \to Z', \\ g''_l : X \times Z'' \to Z''. \end{cases} \quad (3)$$

The given surjections describe the work of this convolution.

Here W′, W″ – the sets of states of I and II Moore subautomata, X – the set of output signals of Moore automaton and input signals of Mealy automaton, Y′ – the set of output signals of I Mealy subautomaton and input signals of II Mealy subautomaton, Y″– the set of output signals of II Mealy subautomaton and input signals of Moore automaton, Z′, Z″ – the sets of states of I and II Mealy subautomata.

Besides the convolution of automata starts operating after the initial states z'_0, z''_0, w'_0, w''_0 are introduced. The implementation of the work of automata convolution can be presented as in Fig. 4:

$$\begin{bmatrix} - \\ - \\ - \\ - \\ - \\ z'_0 \\ z''_0 \end{bmatrix} \Rightarrow \begin{bmatrix} w'_1 \\ w''_1 \\ f_r(w'_1, w''_1) = x_1 \\ f'_l(x_1, z'_0) = y'_1 \\ f''_l(y'_1, z''_0) = y_1 \\ g'_l(x_1, z'_0) = z'_1 \\ g''_l(y'_1, z''_0) = z''_1 \end{bmatrix} \Rightarrow \begin{bmatrix} g'_r(w'_1, y_1) = w'_2 \\ g''_r(w''_1, y_1) = w''_2 \\ f_r(w'_2, w''_2) = x_2 \\ f'_l(x_2, z'_1) = y'_2 \\ f''_l(y'_2, z''_1) = y_2 \\ g'_l(x_2, z'_1) = z'_2 \\ g''_l(y'_2, z''_1) = z''_2 \end{bmatrix} \ldots$$

Fig. 4. The implementation of the work of automata convolution

The physiological models formalization by automata convolution

Let's define the initial states $z'_0 = z''_0 = w'_0 = w''_0 = 0$.

Then the state (number of patient test) of I Mealy subautomaton can be described by such function:

$$g'_l : \quad z'_n = \begin{cases} z'_{n-1} + 1, & if\ z'_{n-1} \neq \varnothing; \\ \varnothing, & else. \end{cases} \quad (4)$$

Mealy automaton II output function f'_l is composite as well: it consists of 3 functions $f'_l = (f'_{l1}; f'_{l2}; f'_{l3})$. The signal of output from I Mealy automaton – input of II Mealy automaton – parameters measured during stress test:

$$y'_n = (y'_{n,1}, y'_{n,2}, y'_{n,1}); \qquad (5)$$

$$f'_{l1}: \quad y'_{n,1} = \begin{cases} RR, & if\ RR_j \neq \varnothing\ and\ z'_n \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (6)$$

$$f'_{l2}: \quad y'_{n,2} = \begin{cases} JT, & if\ JT_j \neq \varnothing\ and\ z'_n \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (7)$$

$$f'_{l3}: \quad y'_{n,3} = \begin{cases} N, & if\ N_j \neq \varnothing\ and\ z'_n \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (8)$$

Here components of vector $y'_n = (y'_{n,1}, y'_{n,2}, y'_{n,1})$ are also the vectors and their components are the discrete data, measured during load period from stress test.

The state (human functional state evaluation) of II Mealy subautomaton can be described by such function:

$$g''_l: \ z''_n = \begin{cases} \frac{1}{k}\sqrt{\Delta y'^{\,2}_{n,1} + \Delta y'^{\,2}_{n,2} + \Delta y'^{\,2}_{n,3}}, & if\ y'_n \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (9)$$

here k – real number, depending on patient gender [5].

The signal of output from Mealy automaton y_n – input of Moore automaton – is a vector, that first component is human functional state evaluation from previous stress test, other component – evaluation of present test:

$$f''_l: \quad y_n = \begin{cases} (z''_{n-1}; z''_n), & if\ y'_n \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (10)$$

The state of I Moore subautomaton is an evaluation of human healthiness state divided to functional groups, according doctors recommendations and practice [3]. It can be described by such function:

$$g'_r: \ w'_{n+1} = \begin{cases} 0, & if\ y_{n,2} = 0; \\ 1, & if\ 0 < y_{n,2} \leq 40; \\ 2, & if\ 40 < y_{n,2} \leq 50; \\ 3, & if\ 50 < y_{n,2} \leq 70; \\ 4, & if\ 70 < y_{n,2} \leq 80; \\ 5, & if\ y_{n,2} > 80; \\ \varnothing, & else. \end{cases} \qquad (11)$$

The state of II Moore subautomaton is an evaluation of human healthiness state dynamics during two tests. It is the comparison of two tests and can help to make decision if the recommended influence is enough effective [7]. So the state of II Moore subautomaton can be described by such function:

$$g''_r: \ w''_{n+1} = \begin{cases} 0, & if\ y_{n,1} = 0; \\ 1, & if\ y_{n,2} < y_{n,1}; \\ 2, & if\ y_{n,2} = y_{n,1}; \\ 3, & if\ y_{n,2} > y_{n,1}; \\ \varnothing, & if\ y_n = \varnothing. \end{cases} \qquad (12)$$

The signal of output from Moore automaton x_{n+1} – is an evaluation of human functional state and evaluation of applied influence (functional state dynamics):

$$f_r: \ x_{n+1} = \begin{cases} w'_{n+1} \# w''_{n+1}, & if\ w'_{n+1}\ and\ w''_{n+1} \neq \varnothing; \\ \varnothing, & else. \end{cases} \qquad (13)$$

Here the symbol "#" denotes the concatenation operation. For example if $w'_{n+1} = 3$ and $w''_{n+1} = 1$ the result $x_{n+1} = 31$, means that now patient functional state is normal, but worse comparing with the previous test – so the applied influence was not suitable.

Conclusions

We have indicated that the functional state variation and dynamics could be formalized and mathematically described by the convolution of Mealy and Moore automata.

The presented model is changeable – we can easily add new components (subautomatons, states, functions) and describe the information streams in more details.

This model could be applied for the automation of diagnosis or could help to organize the feedback between patient functional state and applied influence.

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The statistics claims, that people who are not physically active live shorter and they are ill more often. However, only individual physical activity is useful. Human organism adaptation to physical load peculiarities and opportunities is an actual task of physiology, sports and clinical medicine. For the solution of this task we analyzed the integral health evaluation and formalized effect models. We suggested to formalize and mathematically describe these models by the convolution of Mealy and Moore automata. This model could be applied for the automation of making diagnosis or help to organize the feedback between patient functional state and applied influence. lll. 4, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

К. Бершкене, А. Лукошявичюс, З. Навицкас, А. Вайнорас. Моделирование изменения состояния здоровья человека на продолжительное время // Электроника и электротехника. – Каунас: Технология, 2006. – № 7(71). – P. 73–76.

Современная статистика гласит, что физически пассивные люди болеют чаще и продолжительность их жизни короче. Но это не означает, что любая физическая активность уменьшает заболеваемость и удлиняет жизнь. Адаптивные свойства человеческого организма к физическим нагрузкам являются важным фактором в спортивной медицине, в физиологии и в клинической практике. Для решения этой задачи в работе исследуются модели, описывающие состояние человеческого организма: интегральная модель состояния здоровья и формализированае влияние на человека. В работе приводится методика, как всё это описать с помощью свёртки автоматов Миля и Мура. Предложенная модель может быть так же применена и для описания связи между пациентом и врачом. Ил. 4, библ. 7 (на англиском языке; рефераты на английском, русском и литовском яз.).

K. Berškienė, A. Lukoševičius, Z. Navickas, A. Vainoras. Ilgalaikės sveikatingumo būsenos dinamikos modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 7(71). – P. 73–76.

Šių dienų statistika teigia, kad fiziškai neaktyvūs asmenys serga dažniau ir jų amžius yra trumpesnis, tačiau tai dar visiškai nereiškia, kad bet koks fizinis aktyvumas šį sergamumą sumažina. Žmogaus organizmo adaptacijos prie fizinių krūvių savybės ir ypatybės yra labai svarbus šiandieninės sporto medicinos, fiziologijos ir klinikinės praktikos uždavinys. Šiam uždaviniui spręsti darbe nagrinėjami ilgalaikę asmens sveikatingumo būseną aprašantys modeliai: integralios organizmo reakcijos į fizinį krūvį ir formalizuoto poveikio modeliai. Straipsnyje pateikta metodika, formalizuojanti šiuos du modelius Milio ir Muro automatų sąsūkos pagalba. Pasiūlytas modelis gali būti taikomas sudarant diagnozę, modeliuojant grįžtamąjį ryšį tarp paciento ir gydytojo. Il. 4, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).