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MODEL OF THE ADAPTATION PROCESS OF HUMAN-MACHINE SYSTEMS TO USERS

Means of cursor control, such as a mouse, a keyboard, are the most economic advantageous for build human-computer systems adaptive to users. In this paper the cause of incorrect results in identify individual characteristics of users found: variety combination of affecting factors. The model of generating a dynamics of manipulations by means of cursor control developed. Its simplified variants helped build the model of the adaptation process of human-machine systems to the psycho-emotional states of users and detect its properties.

Keywords: mouse, keyboard, human-computer systems, adaptive system.

Introduction

Modern human-machine systems (HMS) develop friendly, but they do not provide even respond to significant changes of user's states. Introduction of the adaptive systems to psycho-emotional states of users will promote the development of emotional intelligence. This will lead to increased productivity.

Pointing devices (PD) are the least expensive to build such systems. However, identification of users or their individual features exceptionally based on dynamics of manipulations by PD (DMPD) do not always give high results. Adaptive systems, based on DMPD, did not develop.

Materials and methods

In [1] showed that a significant difference in mean values by some signs of DMPD grows up 99% in the neutral state and the lowered attention/reaction state. However, psycho-physiological states depend from many factors also: fatigue, emotion state, stress, expressed propensity to experiencing of certain emotions, self-control, acceptance drinks containing alcohol, caffeine or medications, thyroid illnesses [2], basic events taken place in the world and others.

Graphologists found differences in the handwriting of men and women, although, Picard R. [3] did not confirm significant differences between gender or age groups. Graphologists proved that violations of fine motor skills in some diseases are the cause of specific changes in the handwriting. However, the affect on DMPD length of fingers, muscle tone and others features of a structure the upper extremities of a body did not investigate.

Professional orientation probably affect on DMPD: designers, gamers do motions by the mouse more exactly and quickly, secretaries print more quickly. Changing the type of activity will lead to change in DMPD. Individual pattern will distort after a long absence of daily practice. Skills and individuality of DMPD in course of time will grow.

Thus, among all factors, affecting on DMPD, the user's individual features allocated.

In [4] dependence the dynamics of manipulations by a mouse from technical descriptions of peripheral devices of PC explored. The hypothesis of random dependence was rejected or its authenticity below 90% by acceleration, by speed of motions, by weight, by frequency of questioning mouse port, by permission of monitor's screen. Lepyoshkin O.M. and Skubickij A.V. in [5] showed that 5 users worked most quickly in the middle of the day, a bit slower – in the morning, much slower – in the evening. However, it can be incorrect for other users. The influence of seasonal and week's changes, traumas of hands, terms of work (workplace ergonomics, distracting factors, body poses) on DMPD did not explore.

Consequently, among factors, affecting on DMPD, environmental factors allocated.

Dynamics of manipulations by mouse received during the time from half-second to half an hour or continuous testing [6] with an interval of 10 ms or more, did not take into account pauses in work. Zimmerman P. handled the 67 signs of dynamics, but not all of them or fewer of them did not give meaningful results [7]. Analysis of only speed [8], but in 8 directions, gave errors less than 6%. Forms of data capture from games to questionnaires can distort signs because bring a superfluous emotions, confusion, loss of attention focus. Not objective methods of data capture sometimes used to verification of evaluation of individual features, for example, self-report [9]. Methods of data processing: statistical on the basis discriminant, cluster, factor analysis or artificial neuron networks give errors under 20%. Main limitation of the second group of methods is complication the creation of correct training sample.

For identification used a reference sample. However, the question of the amount of time required to obtain a useful reference sample unresolved. The author is sure half an hour is not enough, given the allocated factors, and the month – more likely. In addition, DMPD researchers indicate about one reference sample but, perhaps, it should be more than one or every day a new one. The author thinks that "fresh" sample obtained in a short time – a more rational decision.

Hence, restrictions imposed by software developers allocated.

Thus, three types of factors affect on DMPD: 1) individual $f(t)$: e – psycho-emotional state, p – physical state, l – level of skills, c – professional orientation, 2) external $z(t)$: b – technical descriptions of manipulator, monitor, w – terms of work, h – the time of day, seasonal and week changes, 3) restrictions imposed by software developer $r(t)$: k – duration of time or length of phrase sufficient to authentication, i – informing signs, n – temporal/spatial segmentation, m – form, method of collection and q – data processing.

The aim of this paper is develop the model the adaptation process of HMS to psycho-emotional states of users by DMPD. To achieve this aim should solve the following problems: 1) identification of factors affecting DMPD, 2) development the model of generating DMPD, 3) implementation the modeling DMPD.

Results

Fundamental model of generating DMPD

Let $X = (x_1(t), \ldots, x_N(t))$ be the set of values of DMPD signs: x_1 – duration of keystrokes, x_2 – pauses between keystrokes, x_3 – amendment on distance that mouse pointer reaches the goal, x_4 – velocity, x_5 – mouse pointer acceleration, x_6 – curvature curve that describes the pointer when mouse moving. Then DMPD represented by the set I: $\{ X \cup MX_i \}$, where MX_i – statistical characteristics of x_i, $i = 1, \ldots 6$.

Fundamental model of generating DMPD represented in Fig. 1. The first two groups of factors directly affect on DMPD and the third affect at the receiving and processing of informative signs.

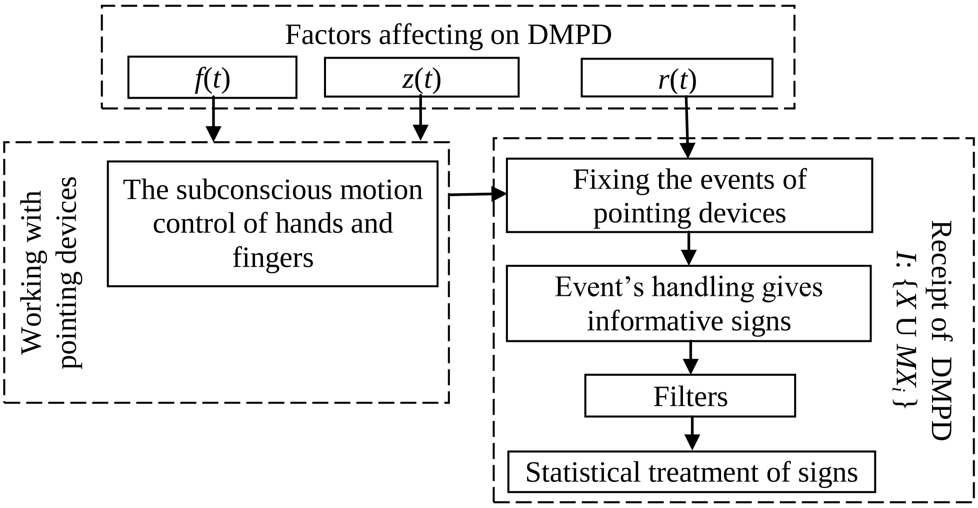

Fig. 1. Fundamental model of generating DMPD

Influencing can be systematic, for example, day's changes or casual – distracting factors. As affecting factors can change over time, the unique DMPD can change.

Let in $f(t)$ be $e = \{e1, e2, e3\}$ – psycho-emotional state, where $e1$ – state of reduced reaction, affect, psychosis, etc., $e2$ – intense emotion, e3 – neutral state; $l = \{l1, l2, l3\}$ – state-level skills: $l1$ – high, $l2$ – medium, $l3$ – low; $c = \{c1, c2, c3\}$ – set formed by professional orientation: $c1$ – designers, $c2$ – secretaries, programmers and etc.; $p = \{p1, p2\}$ – physical condition: $p1$ – user healthy, $p2$ – conversely; in $z(t)$ $h = \{h1, h2, ..., h9\}$ – set the time of day and week: combination of morning, afternoon, evening, Saturday, midweek, day before holiday; $b = \{b1, b2\}$ – the state of the technical characteristics of PD: $b1$ – changed or inconvenient to the user, $b2$ – conversely; $w = \{w1, w2\}$ – set of work terms: $w1$ – no distractions, $w2$ – conversely. The states and their transitions, when exposed to signs, can describe features and then assemble in groups of factors. For example,

$$w = \begin{cases} 1, & \text{if } w1, \\ \frac{1}{\beta} e^{-|t - t_0|}, & \text{if } w2, \end{cases} \quad (1)$$

where t_0 – timing of distractions, β – strength of this factor. However, the proof of the influence of any factor or its shape is a scrupulous work.

Probably, the effect of $f(t)$ and $z(t)$ for various signs is different. For example, a sign of x_2 depends more on skills and x_1 – on the type of the nervous system.

So, factors affecting on DMPD allocated. For each user this effect can be individual such as filters on these factors (Fig. 1). Developed the fundamental model of generation DMPD based on these factors shows at which stage there is an influence. Filters or correction factors to the identified factors will increase the accuracy of identification by PD.

Model of process of generating DMPD in terms of automatic control theory

In Fig. 2 showed the developed model of process of generating DMPD by user in terms of the theory of automatic control. SC – subject of control (human), IOC – intermediate object of control (mouse, keyboard), OC – object of control – the cursor of PD on PC monitor or another digital device which performs the quantization and gives $x(t)$, $f(t)$ – control input, $z(t)$ – disturbances, including a signaling information from the workplace, $g(t)$ – control action: analog signals from human's subconscious to hands for manipulation by PD, $x_c(t)$ – mouse/keyboard events that handled PC from SC, $x(t)$ – discrete signals from the output of OC – values of signs the dynamics of manipulation by PD.

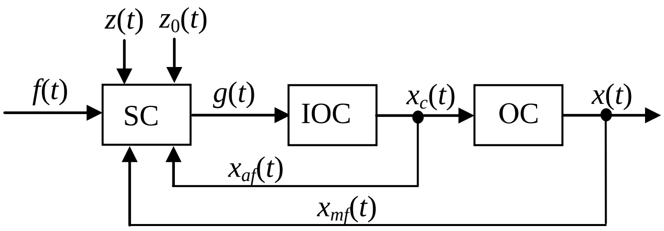

Fig. 2. *The model of generating DMPD*

Description the model of controls DMPD. Internal message of individual will $f(t)$ of user (SC), which is under the influence of external factors $z(t)$, is realized by control a number of subconscious movements. Subconscious SC formed these movements by a signals $g(t)$ to achieve goals using PD (IOC). Human can make a combined control feeling by the mouse/keyboard, looking at the typed characters, controlling the cursor: adjust technical characteristics of mouse, drink stimulating drinks, affect the body posture, etc. (control by perturbation) or correct mistakes, apply more internal efforts (control by exception). In Fig.2 $z_0(t)$ – perturbation influence controlled by human, x_{mf}(t) – main feedback, $x_{af}(t)$ – additional feedback.

For the keyboard writing $x_c(t)$ is a value of time of keyboard events: a stepped aperiodic function, for the mouse dynamics – it's a value of time of the mouse position or the occurrence of events: a stepped function in the system (X, Y, t). Expressions of transition $x_c(t)$ to $x(t)$ are known [1].

Let $g(t)$ – the signal to control "natural" synergies, defined eigenvectors of Lagrange's linearized equations from dynamic model of the human hand. In the nervous system to control the excessive apparatus of muscles and joints generated motor synergies of control commands [10], which are manifested in coordinated changes of joint angles, kinematic synergies, and joint moments, dynamic synergy. Relationship between kinematic and dynamic synergies is defined by a complex dynamic interaction of parts of biomechanical chain. The movement of each segment has an effect on the movement of all others and activation of every muscle movement draws in all segments, but not just those to which this muscle attached.

In [11] showed that the joint could simulate visco-elastic spring with a time delay of 50-100ms. The model with delay times of forces acting on the joints described by the linear equation "PD-perturbation"

$$\ddot{I}_{\lambda}(t) = \ddot{I}_{\lambda}(t-\tau) + S_{\lambda\mu}[(\eta_d^{\mu}(t) - \eta^{\mu}(t-\tau)] + V_{\lambda\mu}[(\dot{\eta}_d^{\mu}(t) - \dot{\eta}^{\mu}(t-\tau)], \qquad (2)$$

where $S_{\lambda\mu}$ – stiffness matrix, $V_{\lambda\mu}$ – viscosity matrix, $\eta^{\mu}(t)$ and $\dot{\eta}^{\mu}(t)$ – joint angles and angular velocity at time *t*, $\eta_d^{\mu}(t)$ and $\dot{\eta}_d^{\mu}(t)$ – desired values of joint angle and angular velocity, τ – a time delay. Articular angles $\eta^{\mu}(t)$, angular velocity $\dot{\eta}^{\mu}(t)$ and angular acceleration $\ddot{\eta}^{\mu}(t)$ calculated according to the registration movement. External forces are given. Masses and moments of inertia of links that are included in the expression for the metric tensor and the Christoffel symbol defined for each human individually using anthropometric tables. Visco-elastic properties of joints – matrix stiffness $S_{\lambda\mu}$ and viscosity $V_{\lambda\mu}$ are defined by the linear regression model applied to equation (2). Visco-elastic properties of the elbow joint at sudden and controlled unloading of the forearm, hand joints two-link model in its purposeful movements [12] calculated this way based on registering of kinematics of movements. However, causes difficulties not only an individual approach. Causes difficulties the calculation of operator that complicated commands of control converts into the output signal $x_c(t)$.

Find the signal conversion operator for SC is difficult, even with the proposed simplified (Fig. 3) representing the input *f*(*t*). Models perception of the external of signal information through hearing, sight, smell, touch and emotion appearance of such effects, the impact of emotions on the kinematics of body movements, describing systemic mechanisms of the brain: mechanisms of consciousness, thinking, are mainly represented in the form of verbal or circuit solutions. Other solutions based on data registration bioelectrical activity areas of the cerebral cortex. For example, simulation of human brain responses to external stimuli first described in [13] by a system of stochastic differential equations, however, the model is based on data from EEG. Artificial neural networks used in the field of artificial intelligence as a simplified model of neural networks in the brain does not reflect its real structure.

Imitation modeling of process of generating DMPD

We apply Imitation modeling because the nature of the processes occurring in the system on Fig.2 not describe in an analytical form. Simplify the model in Fig.2 gives the input sample of standard continuous uniform distribution (Fig. 3). OC is a cursor PD.

Fig.3. Simplified model of generating DMPD

To apply of simulation modeling we find distribution laws x_1, …, x_6. By applying a quantitative method of grouping to each sampling x_j from 10 sets of values of signs *X* taken from three users, and to verify the consent of experimental distribution with theoretical – nonparametric Kolmogorov-Smirnov test we obtain: 1) distribution of x_1 with probability at least 95% identical to the Weibull distribution with sample size $n = 42$ and the selection of parameters, 2) distribution of x_2 with probability at least 95% identical to the Weibull distribution even when $n = 21$, 3) distribution of x_4 with probability at least 90% identical to the exponential distribution when $n = 63$, 4) distribution of x_5 with probability at least 90% identical to the logistic distribution when $n = 63$, 5) distribution of x_6 with probability at least 95% identical to a normal distribution when $n = 63$.

However, imitation modeling gives satisfactory results only "in average". For example, exponential distribution function $F(x) = 1 - e^{-\lambda(x - x_0)}$ strictly increases when generating values x_4 by the method of reverse transformation; its inverse function has the form $F^{-1}(x) = x_0 - \frac{1}{\lambda}\ln(1-x)$. If $U_1,...,U_n$ – sample of a standard continuous uniform distribution when $\hat{x}_1,...,\hat{x}_n$, where $\hat{x}_i = x_0 - \frac{1}{\lambda}\ln(1-U_i)$, $i = 1,...,n$ –

searched sample from the exponential distribution. But test the consent of experimental distribution with the distribution, obtained by numerical simulation, by Kolmogorov-Smirnov on 70 sets of values of signs X by x_4 at neutral state gave: probability of identity at least 90% was in 18% of cases, probability of identity from 90 to 5% – in 65% of cases, probability to reject the consent – in 17% of cases.

Modeling DMPD by method of analysis of electrical circuits

Consider another option. We will give at the input (Fig. 3) *f*(*t*) willed message, decomposing it into components using the Heaviside function 1(*t*). SC = arm + PD + cursor.

Since the will is a mental process and the basic elements of the nervous system are neurons that conduct bioelectrical impulses to simulate use the method of analysis of electrical circuits. The basic assumption – OC has the property of linearity, as in the theory of electrical circuits.

In [14] shown that force F of every motive is determined by the expression:

$$F = pRDGu^{1-\frac{\tau}{\tau_1}}, \tag{3}$$

where p – constant coefficient; R – importance the aim for human; D – power of desire to succeed in different activities; $Gu=I_B/I_C$ – a number that describes the information status of motive at the time of its occurrence: I_C – information about resources necessary to goal, prognostic information; I_B – information about resources that the subject has at a given time (pragmatic information)), $0 < Gu < 1$; τ – time; τ_1 – a time required to achieve the aim.

Taking in (3) for $a = pRD$, $b = Gu$ we obtain:

$$F = ab^{1-\frac{\tau}{\tau_1}}. \tag{4}$$

If we give the influence F on OC at the time $t = 0$ then F equals $F \cdot x(t)$ on OC. If this F apply not at the time $t = 0$, but at the time τ, then F equals $F \cdot x(t-\tau)$ on OC. F can be represented the continuous function in the form

$$f(t) = f(0)\cdot 1(t) + \Delta f_1 \cdot 1(t-\Delta t) + \Delta f_2 \cdot 1(t-2\Delta t) + ... + \Delta f_n \cdot 1(t-n\Delta t). \tag{5}$$

If *f*(*t*) presented in the form of a sequence of functions 1(*t*) then on OC it defined as a sequence of reactions OC to sequence Heaviside functions and has the form

$$u(t) = f(0)\cdot x(t) + \Delta f_1 \cdot x(t-\Delta t) + \Delta f_2 \cdot x(t-2\Delta t) + ... + \Delta f_n \cdot x(t-n\Delta t). \tag{6}$$

If we increase to infinity the number n then the limit of the broken line (5) is the curve (4). Multiplying and dividing both sides of equations (5) and (6) for the increment of time Δt we obtain:

$$f(t) = f(0)\cdot 1(t) + \sum_{i=1}^{n} \frac{\Delta f_n}{\Delta t} 1(t-n\Delta t)\cdot \Delta t, \tag{7}$$

$$u(t) = f(0)\cdot x(t) + \sum_{i=1}^{n} \frac{\Delta f_n}{\Delta t} x(t-n\Delta t)\cdot \Delta t. \tag{8}$$

We move on from the final step of reference Δt to $d\tau \to 0$ when $\Delta t \to 0$. Marked $n \cdot \Delta t = \tau$ we get

$$u(t) = f(0)\cdot x(t) + \int_0^t x(t-\tau)\cdot f'(\tau) d\tau. \tag{9}$$

To find *u*(*t*) we take the distribution law of the relevant sign DMPD as transfer function *x*(*t*) because the form of function *f*(*t*) already known. Integrand (9) by replacing $\tau = t - \theta$ has the form

$$-x(\theta)\cdot f'(t-\theta) d\theta. \tag{10}$$

We get equality which equivalent to (9) when reverse replacing

$$u(t) = f(0)\cdot x(t) + \int_0^t x(\tau)\cdot f'(t-\tau) d\tau. \tag{11}$$

Integrating by parts (9) we get $f(0)\cdot x(t)+\int_0^t x(t-\tau)\cdot f'(\tau)d\tau = f(t)\cdot x(0)+\int_0^t f(\tau)\cdot x'(t-\tau)d\tau$,

from here

$$u(t)= f(t)\cdot x(0)+\int_0^t f(\tau)\cdot x'(t-\tau)d\tau . \qquad (12)$$

The Integral in expression (12) at replacement $\tau = t-\theta$, has the form

$$-\int_t^0 f(t-\theta)\cdot x'(\theta)d\theta . \qquad (13)$$

Applying to (13) the formula of differentiation under the integral sign for the case where the limits of integration variables

$$u(t)=\frac{d}{dt}\int_0^t f(t-\theta)\cdot x(\theta)d\theta \qquad (14)$$

and the substitution $\tau = t-\theta$ we obtain: $u(t)=\frac{d}{dt}\int_0^t f(\tau)\cdot x(t-\tau)d\tau$.

When passing through the OC perturbation F of the form (4) we obtain by (14)

$$u(t)=\frac{d}{dt}\left(ab^{1-\frac{t}{\tau_1}}\cdot\int_0^t ab^{1+\frac{\tau}{\tau_1}}\cdot x(\tau)d\tau \right). \qquad (15)$$

We find the derivative of product (15)

$$u(t)=-\frac{\ln a}{\tau_1}\cdot ab^{1-\frac{t}{\tau_1}}\cdot\int_0^t ab^{1+\frac{\tau}{\tau_1}}\cdot x(\tau)d\tau + ab^{1-\frac{t}{\tau_1}}\cdot\frac{d}{dt}\left(\int_0^t ab^{1+\frac{\tau}{\tau_1}}\cdot x(\tau)d\tau\right). \qquad (16)$$

Applying to (16) the differentiation when limits of integration are variables we obtain $\frac{d}{dt}\int_0^t ab^{1+\frac{\tau}{\tau_1}}\cdot x(\tau)d\tau = ab^{1+\frac{t}{\tau_1}}x(t)$ and

$$u(t)=\frac{-1}{\tau_1}\ln a\cdot a^2 b^{1-\frac{t}{\tau_1}}\cdot\int_0^t b^{1+\frac{\tau}{\tau_1}}\cdot x(\tau)d\tau + a^2b^2x(t) . \qquad (17)$$

Function $u(t)$, which determines the state of F at OC, has the same form as control input $f(t)$. For example, if we put in (2) $p = 1$, $R = 1$, $D = 1$, $Gu = 0.2$ we obtain $u(t)=0.04x(t)$.

The smaller Gu the faster in output achieved sustainable value. The more R and D the slower in output achieved sustainable value. That is, according to (3), too high relevance for human's aims and the power of desire to succeed and a great number of pragmatic information prevents the stability of control by PD. Psychologists claim that the higher the emotional intelligence of man, the faster it will solve problems related to motivation. Therefore, we can speed up performance of employee if supporting or regulate certain emotions in the workplace.

Note that when user manipulates by PD the aim always achieved (excluding significant distractions or when user's in state of subnormal reactions), although, for example, the cursor moves nonlinear, continuous and different paths when performing the same tasks. Given the control of cursor as control for dynamic system could argue that such system is stable since the aim achieved.

Model of the adaptation process of human-machine system to psycho-emotional states

Let there a reference sample DMPD $x_e(t)$ it is difficult to avoid arbitrariness of restrictions established by researcher. We assume that such errors minimized and we ignored them.

In [16] found depending in average of values of attributes DMPD from influence the emotions of joy. When we create HMS that improves the adaptation to user's psycho-emotional states based on DMPD (Fig. 4) with Δx can determine the user's state and apply the appropriate audio-visual influence $z_R(t)$ for the reduction of high emotion or, for example, the affect on PD technical specifications $z_2(t)$. However, when

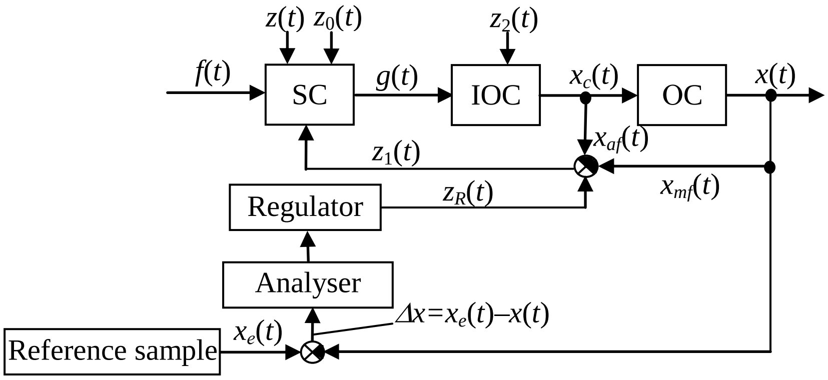

Fig. 4. Model of the automated adaptation process of HMS to psycho-emotional states of SC

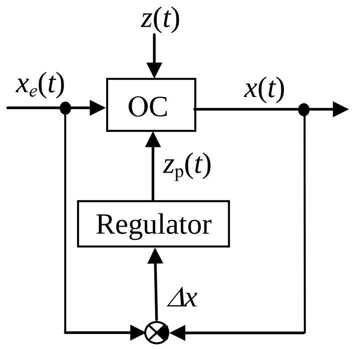

Fig.5. Model of automatic control PD

to expect a working model of the brain is unknown. Consider the model in Fig. 4 (see Fig. 5): let *Woc* be (17), on input of which filed the control input $x_e(t)$. This model will be appropriate only in the automatic control by PD.

Let *Woc* – transfer function OC, *Wioc* – transfer function IOC, *Wsc* – transfer function SC, W_R – transfer function of regulator are known, when state of the process in Fig. 4 describes by the following equations: $g = Wsc \cdot z \cdot f \cdot z_0 \cdot z_1$, $x_c = Wioc \cdot (g + z_2)$, $x = Woc \cdot x_c$, $z_R = W_R \cdot \Delta x$, $\Delta x = x_e - x$, $z_1 = -z_R - x_{mf} - x_{af}$. Solution their with regard to x gives:

$$x = \frac{Woc \cdot Wioc \cdot Wsc \cdot z_2 \cdot z_0 \cdot z \cdot f \cdot (Wp \cdot x_e - x_{mf} - x_{af})}{1 + W_R \cdot Woc \cdot Wioc \cdot Wsc \cdot z_2 \cdot z_0 \cdot z \cdot f}. \qquad (18)$$

If $Wsc \to \infty$ or any of z, f, z_0 or $z_2 \to \infty$ when the properties of link are defined only properties of the feedback loop and $x = x_e - \frac{x_{mf} + x_{af}}{W_R}$. If SC does not provide z_0 ($z_0 = 0$) when $x = 0$; if $x_{mf} = 0$ and $x_{af} = 0$ or $x_{mf} + x_{af} = 0$, but $z_0 \neq 0$, when $x = x_e - \frac{x_e}{1 + W_R \cdot Woc \cdot Wioc \cdot Wsc \cdot z_2 \cdot z_0 \cdot z \cdot f}$. If we provide high gain in the feedback circuit $W_R \to \infty$ then $x = x_e$. However, do $W_R \to \infty$ impossible. After a series of analytic transformations we find that $x = x_e$, where

$$x = -(x_{mf} + x_{af}) \cdot Woc \cdot Wioc \cdot Wsc \cdot z \cdot f \cdot z_0 \cdot z_2. \qquad (19)$$

But affecting of $f(t)$, x_{mf}, ect. (Fig. 4) onto x and x_e will differ. Thus, each sample DMPD unique.

Selection of audiovisual feedback, total to all users in content and force is difficult, thinking on various cultural, religious, social, secular identities. Furthermore, it is necessary to ensure its variety, ease and quality. As a result, feedback – is many hours of content from many short stories that require the use of PC resources.

The identification of states by DMPD gives low results [1,7,9]. Reasons for this are difficulty of forming of emotions and diverse combination of factors affecting on DMPD. Since full responsibility for the possible moral and consequential property damage, including damage to the physical and neuropsychological health at the wrong adaptation to possible incorrect identifiable psycho-emotional state lies on developers – use additional pressure sensors on the keys, cameras, etc. enhance the efficiency of identification states, but also limit the mass application of the proposed model of adaptation.

Conclusions

The aim of this paper attained.

1. The model of generating DMPD – analog-discrete system – developed based on the identified affecting factors. Results of early experiments with user identification by DMPD were obtained without

these factors and therefore inaccurate. Correction coefficients or filters to the identified factors will increase the accuracy of identification by PD.

2. Modeling of generating DMPD by methods of the theory of electrical circuits showed that very high aim importance and the power of desire to succeed obstruct with stability control of PD. Implementing adaptive to specific user's states of HMS raise productivity of labour.

3. The analysis of the developed model of adaptation process of HMS to users based on DMPD showed that the expression (19) would ensure the stability of DMPD. However, DMPD affected from many factors. Components (19) cannot be constant and feedback requires an individual approach, additional studies and costs. Criteria of model's efficiency are possible to formulate according to analysis DMPD.

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