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Method of Data Processing in Information Systems Using Solutions of Differential Equations with Impulse Effect

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Abstract- The article analyzes the qualitative behavior of the system of equations which in general describes the system of the information network, demonstrates the complex nature of the behavior of the system determined by differential equations and conditions of impulse influence. In such systems, some specific effects (change of asymptotic properties of the decision), the coexistence of the periodic decisions caused by conditions of impulse influence can be shown. Periodic decisions can lead to erroneous decisions by the operator of the radio monitoring system or the operator of the search engine. The mathematical apparatus presented in the work will allow taking into account the possibility of periodic solutions of the system of equations that correspond to the description of the information network. Thus to exclude a possibility of an error of the analysis of signals of external influences on an information network.

Keywords- *Impulse Influence, Nonlinear Equation, Parametric Method, Nonparametric Method, Model, Dynamic System*

I. Introduction

With the development of modern natural science and technology, it becomes necessary to study non-linear dynamic systems for which short-term (instantaneous) processes are inherent, or which are under the influence of external forces, the duration of which can be taken when compiling appropriate mathematical models.

Such systems are found, for example, in the theory of information protection, mechanics, aircraft dynamics, mathematical economics, control theory and other fields of science and technology, where you have to study systems influenced by short-term (pulsed) external forces, which are called systems with impulse influence. However, this is especially characteristic of the operation of impulse means of secretly collecting information. What kind of short-term influence on the radio situation, short-term work in a certain radio range.

As it turned out, the presence of impulse influence can significantly complicate the scanning of radio figures, it is even for cases of relatively simple impulse influences. And when modeling, significantly complicate the solution of differential equations. In general, in the presence of impulse influence, the behavior of solutions of differential equations (even linear differential equations with constant coefficients) can be significantly non-linear and significantly different from the behavior of such systems in the absence of impulse influence.

II. ANALYSIS OF LITERARY SOURCES

Methods for analyzing the effects of random impulse signals are divided into two large classes - non-parametric and parametric. Non-parametric methods use only the information contained in the analyzed signal data. Parametric methods provide for some statistical model of effects of random signals, and the analysis process in this case contains determination of parameters of this model [1].

The mathematical formalization of the detection of random impulse signals is the first scientifically justified step in creating the methodological foundations for ensuring the detection of digital means of secretly obtaining information [2 - 4].

Analysis of the theory of solving nonlinear differential equations regarding methods for modeling complex technical systems has shown that there are corresponding scientific works for solving systems based on solving classical differential equations [5 - 7]. In particular, work [8] proposes a mathematical model of the structure of radio monitoring for the 5th generation network (5G) based on the theory of random graphs.

In [9] shows methods of pulse signals detection and generalization. Entry into the base with sequential spectral and other methods of mathematical analysis. However, the issue of signal analysis to detect periodic signals is not touched. As a result, significant mathematical and technical resources are used. Which leads to an increase in the search time for radio tabs.

The issue of studying the appearance of specific effects (changes in the asymptotic properties of the solution, the existence of periodic decisions), due precisely to the requirements of the scientific literature, is not considered.

Based on the above, periodic solutions of nonlinear differential equations of radio monitoring systems with random impulse influence are very important, and the development of a methodology for solving them is relevant.

III. PRESENTING OF THE MAIN MATERIAL

Consider a dynamic system whose operation is described by the Lienard differential equation of the form:

$$\ddot{x}+f(x)\dot{x}+g(x)=0 \quad (1)$$

($x \in M \subset R^3$, M – phase space of the system (1), $t \in R$ – time) and which is prone to instantaneous forces determined by some operator A_t, which at the moments of passage by the moving point of some fixed position $x = x_*$ acts according to the rule $(x,t) \to (t, A_t x)$. Impulse influence in such a system occurs at non-fixed moments of time and increases the amount of motion in the system by a certain amount $I(\dot{x})$, which depends on the speed of the moving point when it passes the position $x = x_*$. Then let's say that $I(y)$,where $y = \dot{x}$, as a function of argument is continuous.

If t_* some time in which the moving point reaches the position $x = x_*$, in which is subjected to pulsed action, the pulsed perturbations of the moving point are recorded [1]:

$$\Delta\frac{dx}{dt}\bigg|_{x=x*}=\frac{dx}{dt}\bigg|_{t=t*+0}-\frac{dx}{dt}\bigg|_{t=t*-0}=A_t x-x=I(\dot{x}) \quad (2)$$

Descriptions of the physical interpretation of Lienard's equation and the characterization of his phase portrait are studied in detail in [3].

Equation (1) is written equivalently to the system

$$\begin{cases}\dot{x}=y, \\ \dot{y}=-g(x)-f(x)y.\end{cases} \quad (3)$$

In the future, the symbols are used

$$F(x)=\int_0^x f(s)ds, \quad G(x)=\int_0^x g(s)ds.$$

Definition. Differential equation (1) satisfying the condition

$$x\,g(x)>0 \quad \text{for} \quad x \neq 0 \quad (4)$$

and

$$f(-x)=-f(x), \quad g(-x)=-g(x) \quad (5)$$

is called according to Opyal a differential equation of type **S**.

We will designate $y_* = \sqrt{2G(x_*)}$.

Suppose that

1^0. The Lienard differential equation (1) will be an equation of type S and satisfies the mind of the existence and unity of the solution.

2^0. Straight line $x = x_*$ — transversal flow (1) everywhere except for the path for which the line is $x = x_*$ is a tangent. In this case, we believe that $I(0)=0$.

3^0. The impulse operator is continuous with respect to variables.

Suppose also that $|\min G(x)|>1$.

Study of the motion of the phase point of the system (1), (2) in [3] built a Poincaré reflection for direct $x = x_*$, which is used to investigate the existence of periodic solutions to the problem (1), (2). It is also shown that the problem of the existence of periodic solutions system (1), (2) is reduced to specifying the existence of periodic and fixed points of some display of the interval in the same interval, which is determined by the formula

$$f(y)=-y+I(-y) \quad (6)$$

where $I(-y)<y, \quad y \neq 0, \quad y=\dot{x}$.

Let us consider the task about existence of periodic solutions of task (1), (2), when pulse action function has the form:

$$I(y)=\begin{cases}(\lambda-1)y-\lambda y_*, & y \geq 0, \\ -(\lambda+1)y-\lambda y_*, & y<0,\end{cases} \quad (7)$$

where $y=\dot{x}$, λ — a certain parameter, wherein $0<\lambda \leq |\min G(x)|$.

Display

$$f(y)=-y+I(-y)=\begin{cases}\lambda(y_*-y), & y \geq 0, \\ \lambda(y_*+y), & y<0,\end{cases} \quad (8)$$

continuous for all $y \in R$ and has the following properties: $0<\lambda<1$ there is only one unbreakable point that is stable; at $1<\lambda \leq |\min G(x)|$ — two fixed points

$$\left\{\frac{\lambda}{1-\lambda}y_*\right\} \text{ and } \left\{\frac{\lambda-\lambda^2}{1-\lambda^2}y_*\right\}$$

and period 2 periodic point:

$$\left\{\frac{\lambda-\lambda^2}{1+\lambda^2}y_*;\quad \frac{\lambda+\lambda^2}{1+\lambda^2}y_*\right\}$$

Points of period 3 for display (8) form two cycles

$$\left\{\frac{\lambda-\lambda^2-\lambda^3}{1+\lambda^3}y_*;\quad \frac{\lambda+\lambda^2-\lambda^3}{1+\lambda^3}y_*;\quad \frac{\lambda+\lambda^2+\lambda^3}{1+\lambda^3}y_*\right\},$$
$$\left\{\frac{\lambda-\lambda^2+\lambda^3}{1-\lambda^3}y_*;\quad \frac{\lambda+\lambda^2-\lambda^3}{1-\lambda^3}y_*;\quad \frac{\lambda-\lambda^2-\lambda^3}{1-\lambda^3}y_*\right\}.$$

Thus, differential equation (1) with impulse action (2), (7), where $y=\dot{x}$, at $1<\lambda\le|\min G(x)|$, has $T(n)$ – periodic solutions are such that the phase point of this system, when moving along the corresponding trajectory, is subjected to exactly impulse effects over a period where is an arbitrary natural number (see picture [2,3]). Points that specify cycles corresponding to periodic solutions of task (1), (7) satisfy Sharkovsky order [9].

Show that the points that form the periodic cycles for the display (8) need to be searched among the fractions of the form

$$y=\frac{P^n(\lambda)}{1\pm\lambda^n}y_* \tag{9}$$

where $P^n(\lambda)$ — numerous, look $P^n(\lambda)=a_n\lambda^n+a_{n-1}\lambda^{n-1}+...+a_2\lambda^2+\lambda,\quad a_i=\pm1,\ i=\overline{2,\ n}$

Prove the equality (9) using the method of mathematical induction. In particular, with $n=2$ we will receive:

$$y=\lambda(y_*\pm\lambda(y_*\pm y))=(\lambda\pm\lambda^2)y_*\pm\lambda^2 y$$

$$(\lambda^2\pm\lambda)y_*=(1\pm\lambda^2)y$$

$$y=\frac{\lambda\pm\lambda^2}{1\pm\lambda^2}y_*=\frac{P^2(\lambda)}{1\pm\lambda^2}y_*$$

Suppose that (9) is true for $n=k$, that is, fair equality:

$$y=\frac{P^k(\lambda)}{1\pm\lambda^k}y_* \tag{10}$$

Using (10) prove that equality (9) is true for $n=k+1$.

Record (10) as $(1\pm\lambda^k)y=P^k(\lambda)y_*$, or that the same,

$$y=P^k(\lambda)y_*\pm\lambda^k y \tag{11}$$

Substituting (11) in (8) we get:

$$y=\lambda(y_*\pm(P^k(\lambda)y_*\pm\lambda^k y))=$$
$$=\lambda y_*\pm\lambda P^k(\lambda)y_*\pm\lambda^{k+1}y=$$
$$=\lambda y_*\pm P^{k+1}(\lambda)y_*\pm\lambda^{k+1}y=$$
$$=P^{k+1}(\lambda)y_*\pm\lambda^{k+1}y,$$

$$y=\frac{P^{k+1}(\lambda)}{1\pm\lambda^{k+1}}y_*$$

thus proved the assertion.

Statement 1. Differential equation (1) with impulse effect (2), (7), where $y=\dot{x}$, at $1<\lambda\le|\min G(x)|$, has $T(n)$ – periodic solutions are such that the phase point of this system, when moving along the corresponding trajectory, is subjected to exactly n impulse impacts over the period, where n – an arbitrary natural number. Moreover, points of influence of pulsed forces corresponding to $T(n)$ – by periodic decision, it is necessary to look among fractions of the type

$$y=\frac{P^n(\lambda)}{1\pm\lambda^n}y_* \tag{9}$$

where $P^n(\lambda)$ — numerous, look $P^n(\lambda)=a_n\lambda^n+a_{n-1}\lambda^{n-1}+...+a_2\lambda^2+\lambda,\quad a_i=\pm1,\ i=\overline{2,\ n}$

Learn more about the view of the periodic display points (8) that correspond to $T(n)$ – periodic solution of the problem (1), (7).

We will build numerous $P^n(\lambda)$ explicitly. Let's start with a point $y=\frac{\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_*$. Apply to this display point (8).

$$f(y)=\lambda\left(y_*\pm\frac{\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_*\right) \tag{12}$$

or

$$f(y)=\lambda y_*\frac{1+\lambda^n\pm(\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n)}{1+\lambda^n}$$

According to claim 1, the multiple fraction in the denominator must contain the degree n, thus the sign before the fraction in (12) will be "+", and $y<0$.

By making the corresponding transformations (12), we get the following point:

$$y=\frac{\lambda+\lambda^2-\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_* \tag{13}$$

and

$$\frac{\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_*<0$$

or that the same

$$\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n<0 \tag{14}$$

By repeating such judgments for (13) we get a point:

$$y=\frac{\lambda+\lambda^2+\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_* \qquad (15)$$

where again $\frac{\lambda+\lambda^2-\lambda^3-\ldots-\lambda^n}{1+\lambda^n}y_*<0$

$$\lambda+\lambda^2-\lambda^3-\ldots-\lambda^n<0 \qquad (16)$$

Continuing similar judgments, we get that if the numerator of the fraction (9) is equal to $1+\lambda^n$, then numerous $P^n(\lambda)$ in the denominator of the corresponding points of the cycle will look:

$$\begin{array}{l}
\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n,\\
\lambda+\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n,\\
\lambda+\lambda^2+\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n,\\
...\quad ...\quad ...\quad ...\quad ...\quad ...\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}-\lambda^{n-1}-\lambda^n,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n.
\end{array} \qquad (17)$$

Also, for λ there must be a fair system of inequality

$$\begin{cases}
\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n<0,\\
\lambda+\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n<0,\\
\lambda+\lambda^2+\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n<0,\\
...\quad ...\quad ...\quad ...\quad ...\quad ...\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}-\lambda^{n-1}-\lambda^n<0,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n<0,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n>0.
\end{cases} \qquad (18)$$

Obviously, in order to number λ satisfies the system of irregularities (18) sufficiently that it satisfies the penultimate inequality of the system (18), that is $\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n<0$. Thus, it can be shown that when n is increased, the interval from which you can select the parameter value is narrowed λ.

Repeating the above judgments for the case where the fraction numerator (9) is $1-\lambda^n$, that is, when the start point looks $y=\frac{\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n}{1-\lambda^n}y_*$, get a representation of the corresponding numerous $P^n(\lambda)$ in its denominator in its denominator. These many will look like:

$$\begin{array}{l}
\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n,\\
\lambda-\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n,\\
\lambda+\lambda^2-\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n,\\
...\quad ...\quad ...\quad ...\quad ...\quad ...\\
\lambda+\lambda^2+\lambda^3+...-\lambda^{n-2}+\lambda^{n-1}+\lambda^n,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}-\lambda^{n-1}+\lambda^n,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n.
\end{array} \qquad (19)$$

In this case, the system of inequalities that determine the interval of the existence of the parameter λ reduced to view:

$$\begin{cases}
\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n<0,\\
\lambda-\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n>0,\\
\lambda+\lambda^2-\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}+\lambda^n>0,\\
...\quad ...\quad ...\quad ...\quad ...\quad ...\\
\lambda+\lambda^2+\lambda^3+...-\lambda^{n-2}+\lambda^{n-1}+\lambda^n>0,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}-\lambda^{n-1}+\lambda^n>0,\\
\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n<0.
\end{cases} \qquad (20)$$

Like the system (18), so that the number λ satisfies the system of irregularities (20) sufficiently that it satisfies the last inequality of the system (20), that is $\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n<0$.

Thus, we obtained for both considered cases the same inequality, which defines the interval for the parameter λ.

Thus, for all $n\geq 3$ $\lambda\in\left(\alpha,\left|\min G(x)\right|\right]$,where α is a solution to the equation

$$r+r^2+r^3+...+r^{n-2}+r^{n-1}-r^n=0$$

at interval $\left(1,\left|\min G(x)\right|\right]$. In particular, with $n=3$ $\alpha=\frac{1+\sqrt{5}}{2}\approx 1,61803$, at $n=4$ $\alpha=\frac{1}{3}+\sqrt[3]{\frac{19}{27}+\frac{\sqrt{33}}{9}}+\sqrt[3]{\frac{19}{27}-\frac{\sqrt{33}}{9}}\approx 1,83928$.

Note that all reasoning is carried out for the case when points were selected as the starting point of the display (8) $y=\frac{\lambda-\lambda^2-\lambda^3-\ldots-\lambda^n}{1\pm\lambda^n}y_*$. If you select a different point as the start point, you get a set of points that define a periodic display cycle (8) different from the above.

Thus, with (17) and (19) it is seen that among the points of periodic cycles of the display period n (8), when the phase point when moving along the phase path of equation (1) is subjected to pulsed action (7) exactly n times in a period there will necessarily be points of the form:

$$\frac{\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n}{1\pm\lambda^n}$$

and

$$\frac{\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n}{1\pm\lambda^n} \quad (21)$$

Using (21), you can find a set of points to display (8) defining the corresponding $T(n)$ – periodic solution of the problem (1), (7).

It should be noted that considering (17) point $\frac{\lambda-\lambda^2}{1-\lambda^2}$, which is the point of period 2, coincides with the fixed point $\frac{\lambda}{1+\lambda}$.

Thus, a fair statement:

Statement 2. Points defining the periodic cycle of the period in the interval $(1, |\min G(x)|]$ to show (8) when the phase point when moving along the phase trajectory of equation (1) is subjected to pulse action (7) exactly once in a period have the form:

$$\frac{\lambda-\lambda^2-\lambda^3-...-\lambda^{n-2}-\lambda^{n-1}-\lambda^n}{1\pm\lambda^n}$$

and

$$\frac{\lambda+\lambda^2+\lambda^3+...+\lambda^{n-2}+\lambda^{n-1}-\lambda^n}{1\pm\lambda^n}.$$

In this case, the interval from which parameter values n are selected will narrow with increasing λ, namely, $\lambda\in(\alpha, |\min G(x)|]$, where solving the equation $r+r^2+r^3+...+r^{n-2}+r^{n-1}-r^n=0$, at interval $(1, |\min G(x)|]$.

Thus, the analysis of the qualitative behavior of the system (1), (2), (8) demonstrates the complex nature of the behavior of systems determined by differential equations and impulse conditions, under which some specific effects can appear in such systems (change in asymptotic properties of the solution (at $t\to\infty$), coexistence of periodic decisions), due precisely to the conditions of impulse influence.

In practice, in information systems for data transmission, to improve reliability and minimize unauthorized interception of data, you can use the following method:

Step 1. Choose $\lambda\in(\alpha, |\min G(x)|]$ according to the conditions of Statement 2.

Step 2. We choose using formulas (21) we find periodic points for the operator (8).

Step 3. Find the solutions of problem (1), (2), (8).

Step 4. Adjust the data transmission mode so that changes in transmission parameters (frequencies in radio signals, phase / amplitude in phase-amplitude modulation of the signal, angle in optical data transmission systems, etc.) occur at the time of pulse forces in the system (1), (2), (8) or that the same moment of change of data transmission parameters was determined by points that correspond to the periodic mode of the operator (8).

Thus, when trying to gain unauthorized access to the information system that transmits data to an external observer, a certain chaos will be seen in the changes in the key parameters of data transmission. This nonlinear behavior of the system is caused by the application of the properties of the system (1), (2), (8). The probability of operative opening of the used mode is extremely low. The use of this technique of information transmission will provide a high level of security of data transmission even through open communication channels.

IV. CONCLUSION

The analysis of the qualitative behavior of the system of equations generally describes a radio monitoring system, demonstrates the complex nature of the behavior of the system determined by differential equations and pulse conditions. In such systems, some specific effects may appear (changing the asymptotic properties of the solution), the coexistence of periodic solutions, due precisely to the conditions of impulse influence. Periodic decisions can lead to erroneous decisions by the radio monitoring system or the operator of the search complex.

The mathematical apparatus presented in the work will allow taking into account the possibility of periodic solutions of the system of equations describing search complexes (radio monitoring complexes), when analyzing the signals of the necessary radiodianine. Thus, the possibility of error of signal analysis by the mathematical apparatus of the radio monitoring system when searching for impulse signals of the means for secretly collecting information is excluded.

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