Transport and Telecommunication, 2016, volume 17, no. 2, 138–143
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.1515/ttj-2016-0013

DEVELOPMENT OF AN INTELLIGENT SYSTEM OF DETERMINATING THE COORDINATES AND THE SPEED OF THE TRAIN

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Dynamic development of the country's transport system leads to the increase of the length of highways, traffic interchange, including places of crossing with the railway. Notification time for crossing is determined by the maximum speed of the train, which is a significant disadvantage of the automatic crossing signaling. In reality the train speed is less than the estimated one, so the idles at transport intersection (crossing) reach 30-30 minutes, creating not only inconveniences to vehicle traffic, but also unfavorable environmental conditions.

In the development of intellectual control system automatic crossing signaling there is applied the principles patterns recognition with lots of informative features and decisive functions with the procedure of "learning" the decisive function "teacher".

Keywords: Transport intersection, railroad crossing, intelligent systems, control of coordinates and speed of the train, approach control section

1. Introduction

The main technical tool to support safety on railroad crossing is automatic crossing signalling, operating by a «strict» algorithm, that is organized inspection section (approach) of certain length before the crossing (up to 2 km), entering the train at the crossing which is closed to motor vehicles. While if the train speed is low (5-10 km/h), the idle of motor vehicles reaches tens of minutes or a few hours (Karpushenko et al., 2011; Evans, 2011; Silla, Kallberg, 2012). Therefore, research in the field of developing intelligent system of determination the coordinates and the speed of the trains at the approach control section and control over protective devices of the crossing, according to the speed and the coordinates of the train in order to reduce the waiting time of drivers of motor vehicles and properly increasing the safety at traffic crossing, is a relevant task.

2. Task statement

To solution the task of developing an intelligent system of determination coordinates needs to complete the existing system crossing signalling with a device determining the coordinates of the train location, its actual speed and turning on signalling and a protective device with a corresponding time adjustment (Rakotonairy et al., 2010; Russell, Norvig, 2003).

The coordinates and speed of trains at the approach control section to the crossing can be determined by using data of continuously varying parameters rail circuit (informative features), dependent on the dynamics of the train traffic, with the subsequent formation of function $d(s) = f(x_1, x_2,...,x_n)$, where $x_1,x_2,...,x_n$ - informative features, the values of which are proportional to the train coordinates at the approach control section. Wherein the first it is needed to determine the array of informative features, then the type and complexity of the function $d(s)$, to investigate the mathematical model of its accurate characteristics and formulate the conditions for its use for continuous monitoring coordinates of the train.

Currently, the most effective solving such tasks are the principles pattern recognition with a high level of formalization (Luther, 2003), which allows implementing recognition procedure at the approach control section to the crossing as programs for a computer. It should be noted that in this case it does not require specially designed discrete control devices, as the use of microprocessors allows continuously generate coordinate using appropriate software. The construction of intelligent system of determination coordinate and speed of the train using the principles pattern recognition produces a number of tasks

The first relates to definition the array of measuring informative features dependent on the coordinate of the train traffic and developing their mathematical models.

The second task is contained in formation decisive function and procedure its study which is needed for the determination of the train coordinates at the approach control section to the crossing.

3. Mathematical models of informative features

The rail line, as a multipole circuit with distributed parameters, is characterized by input and output quantities, depending on the variations of inner primary parameters and on the effects of the train coordinates (Arkatov et al., 2006; Atabekov, 2009). Therefore, as the primary informative features (parameters of approach track circuit) that described the state of the rail line, it is efficient to use:

- amplitudes and phases of voltages and currents at the entrance of the rail line
- amplitude and phase of voltage on the output of the rail line.

Figure 1 shows a diagram of substitution rail circuit with the designation of the primary informative features, dependent on state of approach control section to crossing.

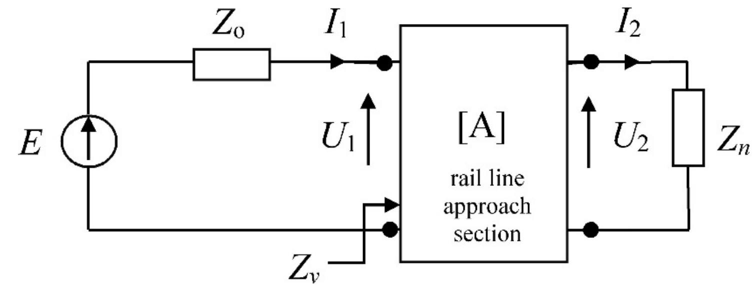

Figure 1. Block diagram of substitution approach track circuit to the crossing

Variety of informative features track circuit can be presented as a pattern state X_{ij}^T in each time:

$$X_{ij}^T = \{U_{1j}, \varphi_{1j}, U_{2j}, \varphi_{2j}, I_{1j}, \psi_{1j}\}, \tag{1}$$

where U_{1ij}, φ_{1ij}, I_{1ij}, ψ_{1ij} - properly amplitudes and phases of the voltage and the current at the input of the rail line approach control section; U_{2ij}, φ_{2ij} - amplitude and phase of the voltage at the output rail line approach control section; $i = 1, 2, ...n$ - the current value of state pattern, dependent on coordinate; j - the state of the rail line:

$$j \equiv \begin{cases} N - \text{free section} \\ S - \text{busy section} \\ O - \text{out of section.} \end{cases}$$

As the train coordinate and speed are determined during the train traffic at the output rail line (Fig. 1 from side Z_n), so $U_{2s}, \varphi_{2s} = 0$, and variety of images, characterizing variation train coordinate have the form:

$$X_{ijs}^T = \{U_{1is}, \varphi_{1is}, I_{1is}, \psi_{1is}\}, \ i = 1, 2, \ldots, n, \tag{2}$$

where i- finding train coordinate; U_{1is}, φ_{1is} - amplitude and phase of the voltage at the input rail line finding train on i- coordinate; I_{1is}, ψ_{1is} - amplitude and phase of the current at the input rail line finding train on i-coordinate.

Quadripole parameters of the rail line approach control section variables, dependent on the state of the rail line and vary continuously due to change in conductivity of insulation rail line, finding train coordinates and discretely, due to breakage of the rail line (Volkov et al., 2005). At that time is particularly lies in fact that the presence on the rail line approach control section to crossing leads to inhomogeneity of conductivity of insulation rail line, i.e. appearance of the area with enhanced conductivity insulation (in the section about 1.5% of the length of the approach control section) (Arkatov et al., 2006). With this diagram of substitution approach track circuit (Fig. 1) should be considered as the cascade connection of two rail quadripoles, namely:

- rail quadripole substitute section of the rail line crossing with coefficients [A_p], length l_p and range of variation of the conductivity of insulation $g_{max\,p} \geq g_p \geq g_{min\,p}$;

- rail quadripole substitute rail line from the crossing to the track circuit receiver with coefficients [A $_o$], the length l_o and range of variation of the conductivity of insulation $g_{\max o} \geq g_o \geq g_{\min o}$.

Therefore, the classical diagram of substitution approach track circuit to the crossing is transformed into diagram of substitution shown in Figure 2.

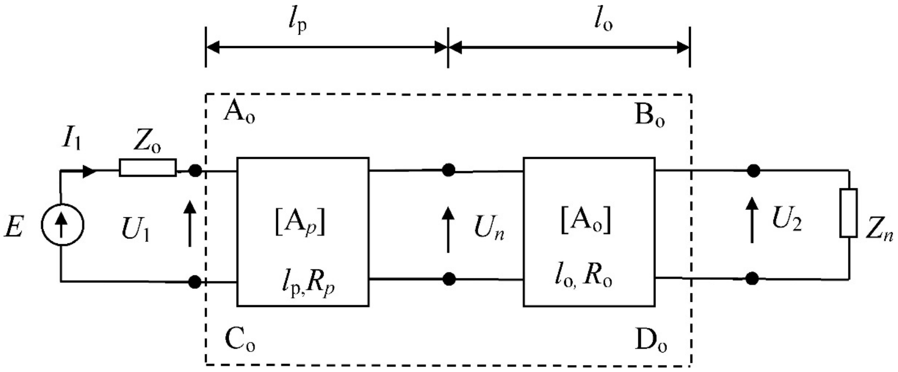

Figure 2. Block diagram of substitution approach track circuit

Matrix parameters rail quadripole replacing the rail line crossing [A_p] has the form (Volkov et al., 2005):

$$\left.\begin{aligned} A_p &= \mathrm{ch}\ \gamma_p l_p;\quad B_p = Z_{vp}\mathrm{sh}\ \gamma_p l_p \\ C_p &= \frac{1}{Z_{vp}}\mathrm{sh}\ \gamma_p l_p;\quad D_p = \mathrm{ch}\ \gamma_p l_p \end{aligned}\right\}, \tag{3}$$

where $Z_{vp} = \sqrt{\dfrac{r_p + j\omega L_p}{g_p + j\omega C_p}}$ - wave resistance of rail line crossing,

$\gamma_p = \sqrt{(r_p + j\omega L_p)\cdot(g_p + j\omega C_p)}$ - coefficient of propagation of an electromagnetic wave in the rail line crossing.

Matrix parameters rail quadripole replacing the rail line from the crossing to the receiver of the rail line (l_o), has the form:

$$\left.\begin{aligned} A_o &= \mathrm{ch}\ \gamma_o l_o;\quad B_o = Z_{vo}\mathrm{sh}\ \gamma_o l_o \\ C_o &= \frac{1}{Z_{vo}}\mathrm{sh}\ \gamma_o l_o;\quad D_o = \mathrm{ch}\ \gamma_o l_o \end{aligned}\right\}, \tag{4}$$

where $Z_{vo} = \sqrt{\dfrac{r_o + j\omega L_o}{g_o + j\omega C_o}}$ wave resistance of rail line crossing,

$\gamma_o = \sqrt{(r_o + j\omega L_o)\cdot(g_o + j\omega C_o)}$ - coefficient of propagation of an electromagnetic wave in the rail line of approach control section.

Coefficients generalized rail quadripole [A_o] are generated by using (3) and (4):

$$\left.\begin{aligned} A_o &= \mathrm{ch}\ \gamma_p l_p \mathrm{ch}\ \gamma_o l_o + Z_{vp}\mathrm{sh}\ \gamma_p l_p \frac{1}{Z_{vo}}\mathrm{sh}\ \gamma_o l_o \\ B_o &= \mathrm{ch}\ \gamma_p l_p Z_{vo}\mathrm{sh}\ \gamma_o l_o + Z_{vp}\mathrm{sh}\ \gamma_p l_p \mathrm{ch}\ \gamma_o l_o \\ C_o &= \frac{1}{Z_{vp}}\mathrm{sh}\ \gamma_p l_p \mathrm{ch}\ \gamma_o l_o + \mathrm{ch}\ \gamma_p l_p \frac{1}{Z_{vo}}\mathrm{sh}\ \gamma_o l_o \\ D_o &= \frac{1}{Z_{vp}}\mathrm{sh}\ \gamma_p l_p Z_{vo}\mathrm{sh}\ \gamma_o l_o + \mathrm{ch}\ \gamma_p l_p \mathrm{ch}\ \gamma_o l_o \end{aligned}\right\}. \tag{5}$$

Communication between the currents and voltages at the beginning and at the end of rail line (as lines with distributed parameters) is determined by ratio (Luther, 2003):

$$\left.\begin{aligned}\dot{U}_1 &= \mathrm{A_o}\dot{U}_2 + \mathrm{B_o}\dot{I}_2\\ \dot{\mathrm{I}}_1 &= \mathrm{C_o}\dot{U}_2 + \mathrm{D_o}\dot{I}_2\end{aligned}\right\}.$$

As $\dot{I}_2 = \dot{U}_2 / Z_n$, long line equation becomes:

$$\left.\begin{aligned}\dot{U}_1 &= \frac{(\mathrm{A_o}Z_n + \mathrm{B_o})\dot{U}_2}{\mathrm{Z_n}}\\ \dot{\mathrm{I}}_1 &= \frac{(\mathrm{C_o}Z_n + \mathrm{D_o})\dot{U}_2}{Z_n}\end{aligned}\right\}. \qquad (6)$$

Similarly,

$$\dot{I}_1 \mathrm{Z}_v = \dot{U}_1,$$

$$\dot{U}_1 = E\text{-}\dot{I}_1 \mathrm{Z_o}.$$

With this in mind, using (3), we obtain:

$$\dot{U}_2 = \frac{EZ_n}{(\mathrm{C_o}\mathrm{Z}_n + \mathrm{D})Z_\mathrm{o} + \mathrm{A_o}\mathrm{Z}_n + \mathrm{B_o}}, \qquad (7)$$

$$\dot{I}_1 = \frac{\mathrm{E}(\mathrm{C_o}\mathrm{Z}_n + \mathrm{D_o})}{(\mathrm{C_o}\mathrm{Z}_n + \mathrm{D_o})\mathrm{Z_o} + \mathrm{A_o}\mathrm{Z}_n + \mathrm{B_o}}, \qquad (8)$$

$$\dot{U}_1 = \frac{E\left(\mathrm{A_o}Z_n + \mathrm{B_o}\right)}{(\mathrm{C_o}\mathrm{Z}_n + \mathrm{D_o})\mathrm{Z_o} + \mathrm{A_o}\mathrm{Z}_n + \mathrm{B_o}}. \qquad (9)$$

Correlations (7), (8) and (9) are the mathematical models of informative features.

4. Determination form of a decisive function

The problem of determining the coordinates of the train is identical to the problem of recognition continuously variable states of dynamic objects.

Continuously variable parameter during the train traffic is its coordinates, hence its speed. Therefore it is needed at the first stage of determination train speed to calculate the variable coordinates of train and then, knowing the distance covered by the train (through the coordinates) at stated interval is easy to calculate its speed.

The basis of methodology for determination of train speed of the principles of recognition is to find the solutions of belonging or confirming measured set of informative features to some predetermined group of coordinates (Tu, Gonzalez, 1978; Tarasov, 1978; Potapov, 2007). It is needed to allow the fact that the variation of informative feature value is influenced by various of perturb factors as changes in conductivity of insulation, rail line resistance so to reduce the perturbation for determination train coordinate, we need to use the information of set of features i.e. informative multidimensional features convert to scalar. Most effective in this sense, it is a method using a decisive function (DF) whose value conforms to the train coordinates, and the arguments are the primary informative features (Tarasov, 1978).

The decisive functions (DF) may be achieved by a variety of methods. In cases where images recognition (set of features) have full of priori information, they can be determined precisely on the basis of this information, but, if images recognition contain less a priori information, so for constructing the recognition system it is needed to use learning procedures, at the first stage assuming selection of the decisive functions of minimum complexity, and then in the implementation of iterative steps to check the precision of determining the train coordinates, to complicate to a predetermined value.

The most extended, having the lowest sensitivity to minor fluctuations the values of features-arguments of function, are linear DF, which can be generalized in the case of nonlinear class boundaries, introducing DF the form (Tu, Gonzalez, 1978):

$$d(X) = C_1f_1(X)+C_2f_2(X)+...+C_kf_k(X)+C_{k+1}=\sum_{i=1}^{k+1} C_if_i(X)+C_i, \qquad (10)$$

where $\{f_i(X)\}$, $i = 1,2,...k$ – real single-valued functions of image (X), $f_{k+1}(X) = 1$, a $(k + 1)$ - number of expansion.

Function representation $\{f_1(X)\}$ as polynomials is one of the most frequent used methods of task of DF. In simple case, these functions are linear, i.e. if $X=(x_1,x_2,...,x_n)^T$, so $\{f_1(X)\}=x_i$, then DF is having the form $d(\mathrm{X})=C^T\mathrm{X}+C_{n+1}$

In order to simplify automatic computing to produce the decisive function is convenient to use orthogonal functions

$$d(X)=\sum_{i=1}^{n} C_{ij}\varphi_j(X),$$

where $\varphi_j(X)=\prod \phi_k(x_i)$ - normalized orthogonally function.

Using a plurality of features (n = 4):

$$\left.\begin{array}{l}
\varphi_1(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_1(x_4),\\
\varphi_2(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_1(x_4),\\
\varphi_3(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_1(x_4),\\
\varphi_4(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_1(x_4),\\
\varphi_5(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_2(x_4),\\
\varphi_6(X)=\phi_1(x_1)\phi_1(x_2)\phi_1(x_3)\phi_2(x_4),\\
\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\\
\varphi_n(X)=\phi_n(x_1)\phi_n(x_2)\phi_n(x_3)\phi_n(x_4)
\end{array}\right\}.$$

As a result of the description of all train coordinates at the approach control section, when all conditions of insulation resistance in the approch control section and at the area of crossing, we get a system of equations of incompatible size $N\times(f+1)^n$ (N - number of origin), and $N >> (f+1)^n$, which are the result of decision of the decisive function coefficients $d(X_S)$.

As a result of the mathematical modeling of informative features, learning decisive functions for the solution of incompatible equations made up of quotient decisive functions corresponding to each coordinate of train location, received the decisive function of determining the train coordinates of the form:

$$\begin{aligned}
d(X_S)=[&-0.0158\cdot\varphi_1\cdot(U_{1S_i})\cdot\varphi_1\cdot(I_{1S_i})+0.0493\cdot\varphi_1\cdot(U_{1S_i})\cdot\varphi_2\cdot(I_{1S_i})-0.1639\cdot\varphi_1\cdot(U_{1S_i})\cdot\varphi_3\cdot(I_{1S_i})+\\
&+0.1511\cdot\varphi_1\cdot(U_{1S_i})\cdot\varphi_4\cdot(I_{1S_i})-0.0378\cdot\varphi_1\cdot(U_{1S_i})\cdot\varphi_5\cdot(I_{1S_i})+\\
&+0.1433\cdot\varphi_2\cdot(U_{1S_i})\cdot\varphi_1\cdot(I_{1S_i})-0.396\cdot\varphi_2\cdot(U_{1S_i})\cdot\varphi_2\cdot(I_{1S_i})+1.347\cdot\varphi_2\cdot(U_{1S_i})\cdot\varphi_3\cdot(I_{1S_i})-\\
&-1.1755\cdot\varphi_2\cdot(U_{1S_i})\cdot\varphi_4\cdot(I_{1S_i})+0.2575\cdot\varphi_2\cdot(U_{1S_i})\cdot\varphi_5\cdot(I_{1S_i})-\\
&-0.3719\cdot\varphi_3\cdot(U_{1S_i})\cdot\varphi_1\cdot(I_{1S_i})+0.8733\cdot\varphi_3\cdot(U_{1S_i})\cdot\varphi_2\cdot(I_{1S_i})-3.1026\cdot\varphi_3\cdot(U_{1S_i})\cdot\varphi_3\cdot(I_{1S_i})+\\
&+2.5245\cdot\varphi_3\cdot(U_{1S_i})\cdot\varphi_4\cdot(I_{1S_i})-0.4668\cdot\varphi_3\cdot(U_{1S_i})\cdot\varphi_5\cdot(I_{1S_i})+\\
&+0.384\cdot\varphi_4\cdot(U_{1S_i})\cdot\varphi_1\cdot(I_{1S_i})-0.7342\cdot\varphi_4\cdot(U_{1S_i})\cdot\varphi_2\cdot(I_{1S_i})+2.7602\cdot\varphi_4\cdot(U_{1S_i})\cdot\varphi_3\cdot(I_{1S_i})-\\
&-2.0196\cdot\varphi_4\cdot(U_{1S_i})\cdot\varphi_4\cdot(I_{1S_i})+0.2648\cdot\varphi_4\cdot(U_{1S_i})\cdot\varphi_5\cdot(I_{1S_i})-\\
&-0.1419\cdot\varphi_5\cdot(U_{1S_i})\cdot\varphi_1\cdot(I_{1S_i})+0.2009\cdot\varphi_5\cdot(U_{1S_i})\cdot\varphi_2\cdot(I_{1S_i})-0.8469\cdot\varphi_5\cdot(U_{1S_i})\cdot\varphi_3\cdot(I_{1S_i})+\\
&+0.5252\cdot\varphi_5\cdot(U_{1S_i})\cdot\varphi_4\cdot(I_{1S_i})-0.0279\cdot\varphi_5\cdot(U_{1S_i})\cdot\varphi_5\cdot(I_{1S_i})]\cdot10^8
\end{aligned}$$

Knowing the train coordinate at any time of the approach control section, its speed is determined by the formula:

$$\vartheta_{\Pi\, i} = \frac{d(X_{S_i}) - d(X_{S_i - 1})}{\Delta t},$$

where ϑ - the train speed on *i* time moment, $d(X_{S_i})$ - current train coordinateat the approach control section, $d(X_{S_i-1})$ - train coordinate in the previous point of time, Δt - the time interval in which the change of train coordinate is occurred from $d(X_{S_i-1})$ to $d(X_{S_i})$.

5. Conclusion

An intelligent system of identification of the train coordinates and speed at the approach of the control section to the crossings is realized by using the decisive function of orthogonal Laguerre polynomial, where signal current frequency inquiry of 50 Hz.

For accuracy of determining the train coordinates and speed at the approach control section is significantly affected by the complexity of the decisive function. Computational experiments revealed that for the proper determination of the train coordinates at the approach control section is enough the fourth degree of the complexity of the decisive function.

Researches of the implemented device have shown that the maximum error in determining the coordinates of train location amounts to not more than 6.9% (30m) at the coordinate of 1500 m. from the crossing and is reduced to 0.1% (0.1 m) at train approach to the crossing.

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