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Poboljšanje tačnosti informacija pri testiranju građevinskih i putnih mašina

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Ovaj rad predstavlja metodu za poboljšanje pouzdanosti merenja podataka tokom ispitivanja građevinskih i putnih mašina.

Ključne reči: senzor, inverzni problemi, genetski algoritam

1. UVODNA RAZMATRANJA

Različiti parametri građevinskih i putnih mašina prilikom isptivanja mere se pomoću različitih senzora. Mnogi senzori su inercijalni, pa se njihove izlazne karakteristike signala mogu značajno razlikovati od ulaznih. Shodno tome, stvaraju se uslovi za donošenje pogrešnih odluka o rezultatima ispitivanja kao i sumnje u tačnost dobijenih informacija. Iz tog razloga potrebno je proceniti karakteristike izlaznog i ulaznog signala senzora.

Slični problemi se odnose i na inverzne probleme [1, 2]. Pretpostavljamo da se signal poznat na izlazu senzora, a impulsni odziv ili karakteristika prenosa ovog senzora je nepoznata. Pri ovakvoj formulaciji problema procena ulaznog signala je praktično nerešiva. Iz tog razloga koristićemo prethodne informacije o nekim karakteristikama senzora. Naročito verujemo da bi oblik senzorskog impulsnog odziva mogao da se napiše kao funkcija opšteg oblika, npr. u obliku

$$h(t)=\begin{cases}\dfrac{k}{\lambda}\left(\dfrac{t}{\lambda}\right)^{k-1}e^{-\left(\frac{t}{\lambda}\right)^{k}}, & t\ge 0,\\ 0, & t<0,\end{cases} \qquad (1)$$

pri čemu su: λ, k - nepoznati parametri koji karakterišu oblik impulsnog odziva.

Proizvoljan ulazni signal može se proširiti u Karhunen - Loeve niz [3]. U tom slučaju, pojedinačna realizacija ulaznog signala sa n-dimenzionalnom predstavljanjem ima oblik

$$x(t)=\sum_{i=1}^{n}a_i\psi_i(t) \qquad (2)$$

U izrazu (2) slučajni koeficijenti niza su nepoznati, dok funkcije $\psi_i(t)$ stvaraju ortonormalnu osnovu i bira ih istraživač.

Realizacija izlaznog signala linearnog pretvarača data je kao

$$y(t)=\int_{-\infty}^{\infty}h(\tau)x(t-\tau)d\tau+n(t), \qquad (3)$$

gde su:
$h(t)$ - impulsni odziv senzora i $n(t)$ - dodatni slučajni proces (buka), koji pretpostavljamo kao beli Gausov šum.

Uzimajući u obzir (1) i (2), izraz (3) se može predstaviti u obliku

$$y(t)=\int_{-\infty}^{\infty}h(\tau)\sum_{i=1}^{n}a_i\psi_i(t-\tau)d\tau+ +n(t). \qquad (4)$$

U izrazu (4) poznajemo izlazni signal $y(t)$ i funkcije $\psi_k(t)$. Ovaj izraz uključuje n+2 nepoznata parametra, a među njima n koeficijenta su slučajni. Njihov broj moguće je smanjiti u slučaju kada je oblik ulaznog signala $x(t)$ jednostavan.

U matematičkoj formulaciji problem definisanja nepoznatih koeficijenata svodi se na problem minimizacije za svaku realizaciju izlaznog signala i buke.

$$J(a_1,...,a_n,...)=\int_{-\infty}^{\infty}[y(t)- -\int_{-\infty}^{\infty}h(\tau)\sum_{i=1}^{n}a_i\psi_i(t-\tau)d\tau-n(t)]^2\,dt \qquad (5)$$

Realizacija buke je kompjuterski simulirana. Izraz (5) sadrži razliku između poznatog izlaznog signala i njegove aproksimacije predstavljene sumom.

2. FUNKCIONALNA MINIMIZACIJA

Problem funkcionalne (5) minimizacije sa velikim brojem nepoznatih koeficijenata a_i može se rešiti korišćenjem globalnih metoda slučajnog pretraživanja, npr. genetski algoritam. Pomoću ovog algoritma dobili smo sve potrebne koeficijente i zapravo rešili problem identifikacije senzora (senzorskog impulsnog odziva), kao i problem obrade "slepog" signala, tj. signala na ulazu pretvarača.

Pokažimo validnost predloženog metoda. U tu svrhu ćemo koristiti matematički model senzora (1) i primer ulaznog signala (Slika 1) koji možemo smatrati standardnim za ovaj problem.

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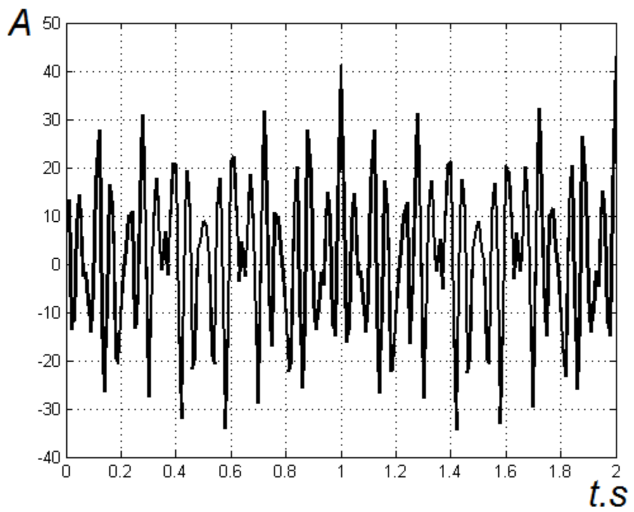


Slika 1: Primer ulaznog signala

Kao ortonormalnu funkciju biramo trigonometrijske funkcije analogno generalizovanom Fourierovom nizu. U ovom slučaju je lako odrediti koeficijente serije (2). Izlazni signal $y(t)$ je izveden iz dve date funkcije integracijom i tada se rešava inverzni problem određivanja koeficijenata. Ovi koeficijenti, kao što smo pokazali, poznati su po tome što opisuju standardni ulazni signal.

Kao integralna karakteristika validnosti rezultata koristili smo ugao u funkcionalnom prostoru između date funkcije $x(t)$ i ponovo izračunatog signala $x_r(t)$ [5].

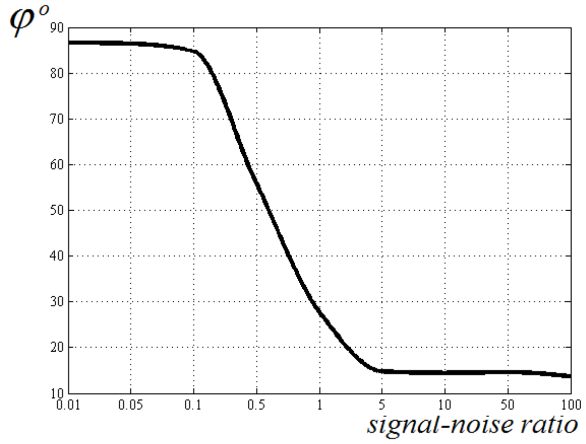
$$\varphi = \arccos \frac{\int_{-\infty}^{\infty} x(t) x_r(t) dt}{\sqrt{\int_{-\infty}^{\infty} x^2(t) dt} \sqrt{\int_{-\infty}^{\infty} x_r^{\,2}(t) dt}}. \qquad (6)$$

Minimiziranje funkcije (5) izvršeno je upotrebom genetskog algoritma. Nakon određivanja globalnog minimuma funkcije (5) odredili smo koeficijente u Karhunen - Loeve nizu i parametre impulsa (1), a zatim definisali oblik ulaznog signala. Shodno tome, bilo je moguće odrediti ugao između dobijenog signala i datog signala. Zavisno od odnosa signala i šuma, ovaj ugao se menja kao što je prikazano na slici 2.

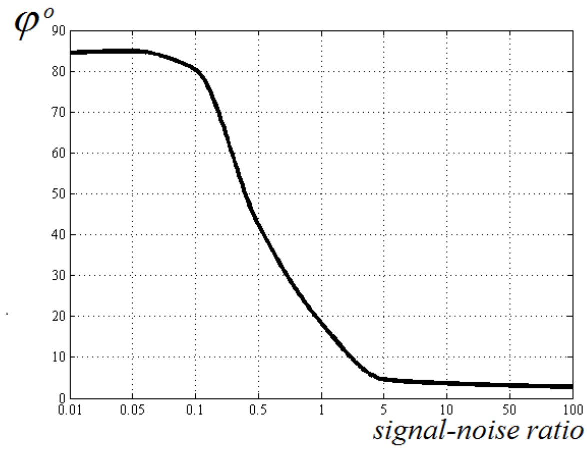
Slično tome, ugao između poznatog i preračunatog impulsnog odziva prikazan je na slici 3.

Stoga, za dovoljno preciznu rekonstrukciju signala na ulazu odnos signala i šuma treba da pređe vrednost od oko pet.

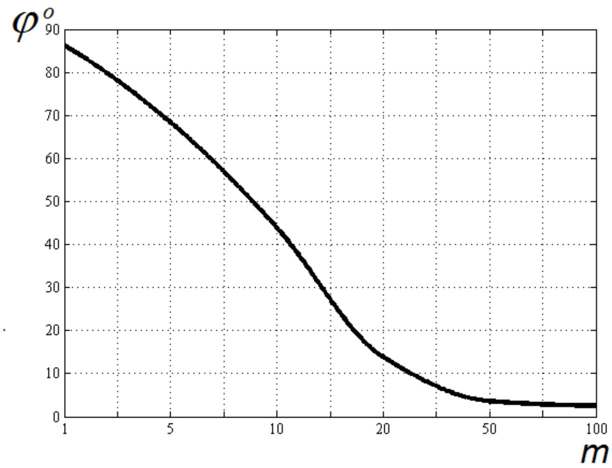
Tačnost proračuna takođe u velikoj meri zavisi od ispravnog izbora broja koeficijenta za opis nepoznatog ulaznog signala i impulsnog odziva senzora kao što je prikazano na slikama 4, 5.



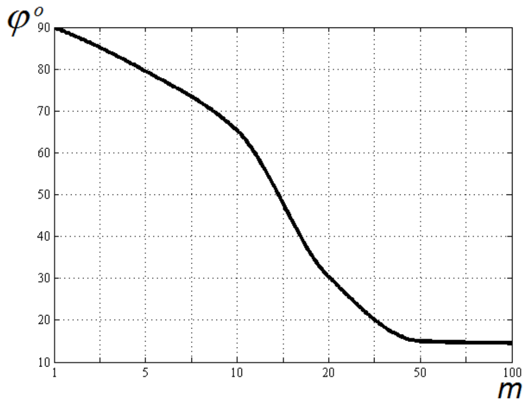
Slika 2: Zavisnost ugla između ulaznog i preračunaog signala od odnosa signal-šum



Slika 3: Zavisnost ugla između poznatog i preračunatog odziva impulsa senzora od odnosa signala – šuma

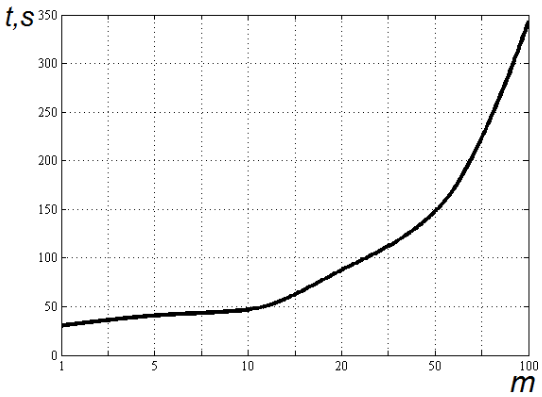


Slika 4: Zavisnost ugla između ulaznog signala i preračunatog signala od broja slučajnih koeficijenata



Slika 5: Zavisnost ugla između poznatog i preračunatog impulsnog odziva senzora od broja slučajnih koeficijenata

Vreme računanja impulsnog odziva senzora i realizacija ulaznog signala zavise od mnogih faktora. Uključuju složenost ulaznog signala i oblika odziva kao i prethodne informacije o njima. Sve veći broj koeficijenata dovodi do dužeg računanja (slika 6).



Slika 6: Zavisnost vremena računanja od broja slučajnih koeficijenata

ZAKLJUČAK

Dakle, rezultati simulacije pokazuju visok nivo tačnosti rekonstrukcije ulaznog signala i odziva senzora. Međutim, potrebno je neko vreme zbog karakteristika stohastičkog određivanja ekstrema u genetskim algoritamima. To komplikuje primenu ove metode u stvarnom radu na građevinskim i putnim mašinama. Da bismo poboljšali tačnost proračuna moramo imati prethodne informacije o obliku impulsnog odziva senzora.

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Improving the Information Accuracy in Building and Road Machines

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This article presents a new method for improving the reliability of data measurements while testing building and road machines.

Keywords: sensor, inverse problems, genetic algorithm.

1. INTRODUCTION

Various important parameters of building and road machines are measured in testing with using different sensors. Many sensors are inertial, therefore their output characteristics of signals can differ greatly from the input ones. Consequently, there are conditions for making wrong decisions on test results and doubts on the accuracy of information obtained. Thus, we might estimate both output and input signal characteristics of the sensor.

Similar problems relate to inverse problems [1,2]. We assume that a signal is exactly known at the output of the sensor and the impulse response or transfer characteristic of this sensor is unknown. In this formulation, the problem of input signal estimation is unsolvable. Therefore, we shall use a priori information about some characteristics of a sensor. In particular, we believe that the form of sensor impulse response could be written as function of the general form, for example,

$$h(t)=\begin{cases}\dfrac{k}{\lambda}\left(\dfrac{t}{\lambda}\right)^{k-1}e^{-\left(\frac{t}{\lambda}\right)^{k}}, & t\geq 0,\\ 0, & t<0,\end{cases} \tag{1}$$

where are: λ, k - the unknown parameters that characterize the shape of the impulse response.

The random input signal can be expanded into a Karhunen - Loeve series [3]. An individual realization of the input signal with an n-dimensional representation

$$x(t)=\sum_{i=1}^{n}a_i\psi_i(t) \tag{2}$$

In expression (2) random coefficients a_i of this series are unknown, functions $\psi_i(t)$ create an orthonormal basis and are selected by the researcher.

The realization of the output signal of linear transducer

$$y(t)=\int_{-\infty}^{\infty}h(\tau)x(t-\tau)d\tau+n(t), \tag{3}$$

where are:

$h(t)$ - the impulse response of the sensor and $n(t)$ - an additive random process (noise), which we assume as white Gaussian noise.

Taking into account (1) and (2) the expression (3) can be written as

$$y(t)=\int_{-\infty}^{\infty}h(\tau)\sum_{i=1}^{n}a_i\psi_i(t-\tau)d\tau+ +n(t). \tag{4}$$

In expression (4) we know the output signal $y(t)$ and functions $\psi_k(t)$. This expression includes n+2 unknown parameters, and among them n coefficients are random. Their number is possible to reduce in case when the form of an input signal $x(t)$ is simple.

In the mathematical formulation the problem of the unknown coefficients evaluation comes to the problem of minimization of the functional

$$J(a_1,...,a_n,...)=\int_{-\infty}^{\infty}[y(t)- -\int_{-\infty}^{\infty}h(\tau)\sum_{i=1}^{n}a_i\psi_i(t-\tau)d\tau-n(t)]^2\,dt \tag{5}$$

for each realization of the output signal and noise. Realization of noise is computer simulated. The expression (5) contains difference between the known output signal and its approximation represented by the sum.

2. THE FUNCTIONAL MINIMIZATION

The problem of the functional (5) minimization with a large number of unknown coefficients a_i can be solved by using of global random search methods, e. g. a genetic algorithm. By means of this algorithm we obtained all necessary coefficients and actually solved the problem of sensor identification (evaluation of sensor impulse response), as well as the problem of "blind" signal processing, i.e. evaluation of signal at transducer input.

Let's show the validity of the proposed method. For this purpose, we shall use the mathematical model of the sensor (1) and the example of input signal realization

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(Figure1), that we can consider as a standard one for this problem.

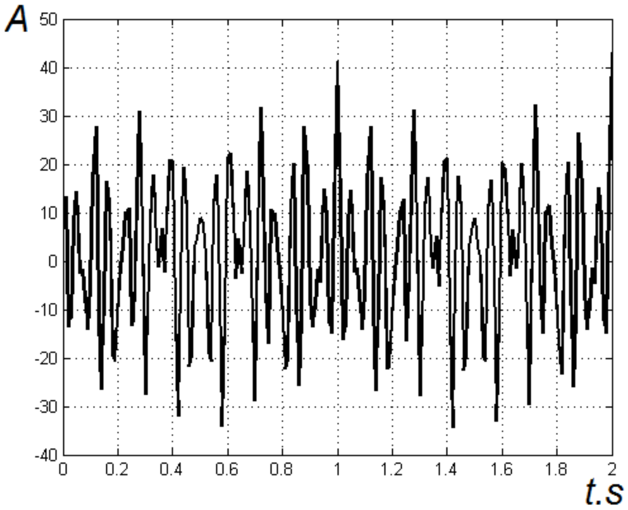

Figure 1: The example of input signal

As an orthonormal function, we choose the trigonometric functions by analogy with a generalized Fourier series. In this case, it is easy to determine the coefficients of series (2). An output signal $y(t)$ is computed by using the convolution equation, and then the inverse problem of the coefficients evaluation is solved. These coefficients, as we have shown, are known because they describe the standard input signal.

As the integral characteristic of the validity of the receiving results, we used the angle in a functional space between a given function $x(t)$ and recalculated signal $x_r(t)$ [5].

$$\varphi = \arccos \frac{\int_{-\infty}^{\infty} x(t) x_r(t) dt}{\sqrt{\int_{-\infty}^{\infty} x^2(t) dt} \sqrt{\int_{-\infty}^{\infty} x_r^{\,2}(t) dt}}. \qquad (6)$$

Minimizing the function (5) was carried out by using a genetic algorithm. After finding the global minimum of (5) we determined the coefficients in the Karhunen - Loeve expansion and parameters of the impulse response (1) and then defined the realization of the input signal.

Consequently, it was possible to determine the angle between the signal obtained and the given one. Depending on the signal-noise ratio, this angle is changed as shown in Figure 2.

Similarly, the angle between the known and the recalculated sensor impulse response is represented in Figure 3.

Thus, for sufficiently accurate reconstruction of the signal at the input of sensor signal to noise ratio should exceed the value of about five.

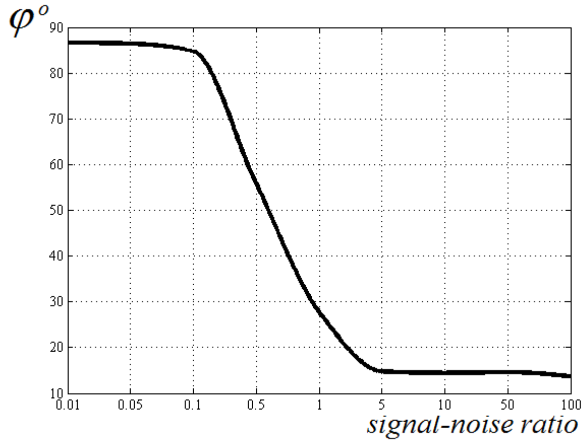

Figure 2: Dependence of the angle between the input signal realization and the recalculated signal on signal-noise ratio

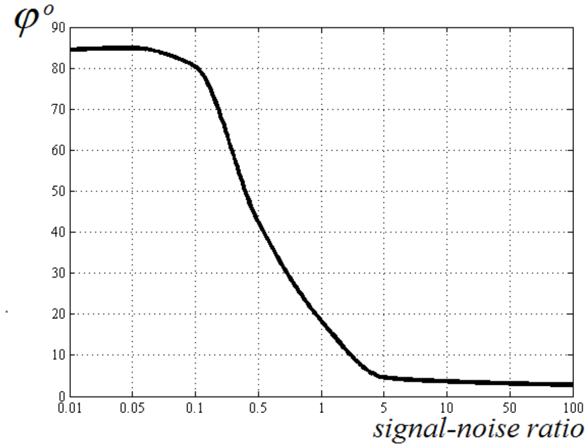

Figure 3: Dependence of the angle between the known and the recalculated sensor impulse response on signal-noise ratio

Calculation accuracy is also largely depended on the correct choice of the coefficient number to describe the unknown input signal and sensor impulse response as shown in Figures 4, 5.

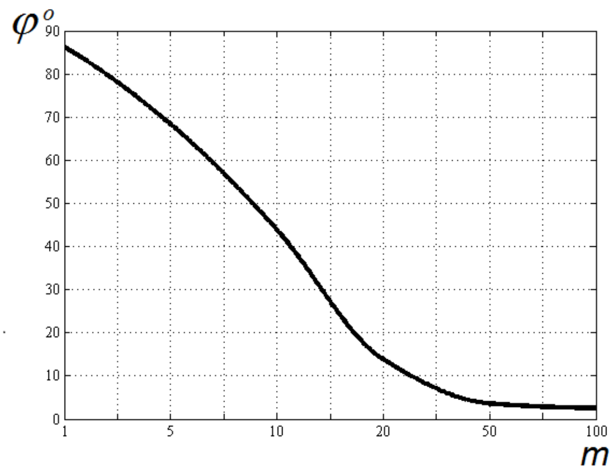

Figure 4: Dependence of the angle between the input signal realization and recalculated signal on the number of random coefficients

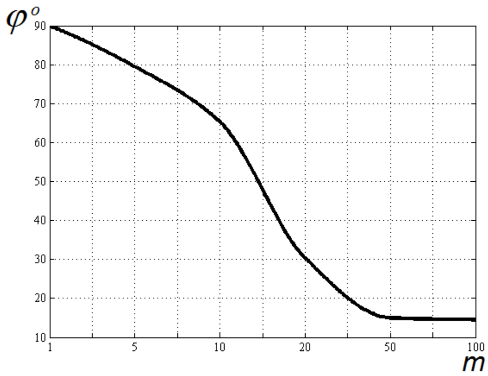

Figure 5: Dependence of the angle between the known and recalculated impulse response of the sensor on the number of random coefficients

Computation time of sensor impulse response and realization of the input signal depends on many factors. They include the complexity of the input signal and the impulse response form as well as a priori information about them. The increasing number of coefficients leads to longer computation time (Figure 6).

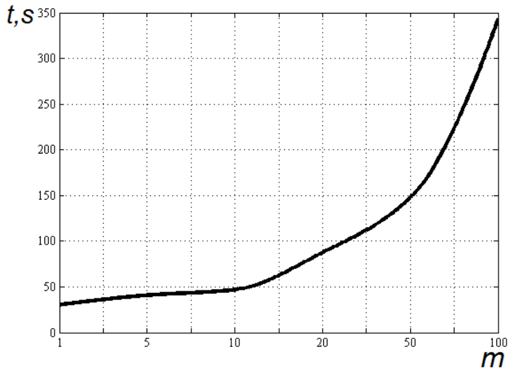

Figure 6: Dependence of the calculation time on the number of random coefficients

3. CONCLUSION

Thus, the simulation results show a high level of accuracy of the input signal reconstruction and the sensor impulse response. However, it takes some time because of the features of stochastic search of the extremum in genetic algorithms. It complicates the application of the method in real work of building and road machines. To improve the accuracy of calculations we must have a priori information about the form of the impulse response of the sensor.

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