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Noise Signal Recognition and Noise Reduction Algorithm of Ships

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ABSTRACT

Based on the study of the sensing property of fiber bragg grating (FBG) sensor network, this paper takes hybrid wavelength division/time division multiplexing sensor network with high-capacity FBG as the research object to study noise source, noise category and traditional noise reduction algorithm. In accordance with the characteristic of crosstalk accumulation noise in the network, this paper proposes LCEEMD-LWT signal processing method, which uses the local complementary ensemble empirical mean decomposition (LCEEMD) method for signal preprocessing, and then adopts LWT technology to refine high-frequency signal and solve the related problems. Then this paper put forwards detrended fluctuation analysis (DFA) to evaluate the sensing signal of high-capacity FBG, preprocesses the sensing signal by LCEEWD-LWT method, and conducts a temperature sensing experiment. The average temperature error of the demodulating system is reduced from 0.2923℃ to 0.2357℃, which not only overcomes the shortcoming that the traditional signal processing method is not meticulous for high-frequency signal processing, but also avoids the problem that the signal processing time is too long, exerting a good effect on the signal pre-processing of high-capacity FBG. The method in this paper has certain theoretical and technical reference value for the signal processing and the improvement of sensing property of high-capacity FBG sensing demodulating system in engineering application.

1. INTRODUCTION

Optical fiber sensing is a data processing technology that uses spectral signal as information communication medium to sense and transmit external information. Optical fiber has been widely used in practical engineering for its high sensitivity, small size, convenience, and accurate sensing. The advance of FBG sensing technology also greatly improves the commercial value, and promotes the expansion of application fields and the improvement of economic benefits.

Nowadays, the research and development of FBG sensor grid with long distance, high capacity, high precision and meshing characteristics has become a hot topic in the communication field. In the future sensor application field, it is of far-reaching significance for China to make FBG sensing technology a key research subject for the strategic position in the world in the future

Although the reflectivity has greatly reduced the pollution of noise to the system, in the practical engineering application, a large amount of noise accumulation will still interfere with the sensing accuracy, thus causing errors in the production practice and hindering the development of optical fiber sensing field. Thus, it is of great significance to study the signal processing of FBG sensor grid.

Zeh [1] proposed the linear phase operator (LPO) technology to test the sensing signal by studying the sensing technique of FBG sensor. After the simulation testing, under the condition of very serious noise interference, the performance of this technology can still be used stably, improving the resolution ratio to three times that of traditional detecting algorithm.

Crockett et al. [2] put forward a method for denoising narrow band optical signal at the kHz and MHz levels. It has been proved that the method is robust to the potential drift of signal processing center frequency, superior to traditional narrow band filter.

The nonlinear and non-stationary characteristics of high-capacity FBG sensing signal are analyzed, and DFA algorithm is proposed to evaluate high-capacity FBG sensing signals. In order to detect the quality of the processed signal thoroughly, the signal deviation degree, similarity degree and signal integrity degree after noise reduction are tested and compared, and good results are obtained in terms of signal-to-noise ratio, root-mean-square error, correlation coefficient and residual error.

For the noise interference in the process of FBG demodulation, some researches by using the digital signal processor TMS320VC5402, performed real-time wavelet denoising. The experimental result of FBG temperature demodulation shows that the proposed method can improve the linearity of the demodulating system by 0.98% and has the ability to improve the demodulation accuracy to a certain extent [3]. However, there is a lack of adaptive signal processing and demodulation.

Zhu [4] proposed a signal processing method combining wavelet packet with adaptive complete set empirical mode decomposition (EMD) algorithm. The simulation experiment verifies that the proposed method has good noise reduction effect and practical value for super-weak FBG sensor network .

Starting from the theoretical model and principle of FBG sensor network, the sensing signal processing of hybrid multiplexing network, the signal quality evaluation index system and the demodulating system testing, signal sensing mode and signal processing method are studied to improve the performance of FBG sensing system. In this paper, the reflectance spectrum of FBG is established and simulated, and the relationship between temperature, stress and central wavelength of FBG is analyzed. DFA algorithm is applied to evaluate the characteristics of high-capacity FBG sensing signal, and the significant advantages of the signal processing method proposed in this paper are verified.

2. OVERALL STUDY AND DESIGN OF THE SYSTEM

2.1 Structural analysis of the system

The active heave compensation control system is a system for controlling the steady state of a ship by means of the ship's power, in which the common devices include hydraulic pump and motors (Figure 1). In the process of operation, the compensation system usually relies on feedback control and feedforward control technologies. The whole system is characterized by strong anti-interference ability and good adaptability, which can meet the requirements of high compensation precision and high stability. However, due to the large power consumption of the active heave compensation control system, technical research and in-depth development of the system have become the focus of the industry [5, 6]. In order to improve the real-time signal efficiency of photoelectric field, a real-time signal processing system for non-equidistant two-way communication of photoelectric field is designed.

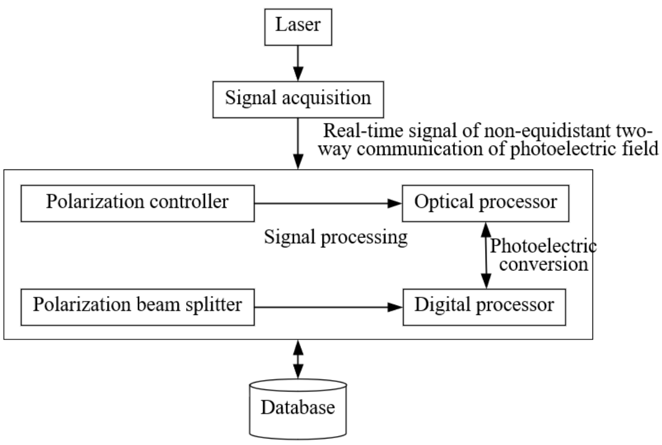

Figure 1. Overall structure of the system

Upon signal processing after performing the filtering processing, a section of resonance arc is gained on the complex plane, and then the circle center and circle are obtained by fitting the resonance arc. The phase information cannot obtained by directly fitting the circle and the circle center, so it is necessary to carry out coordinate transformation on the circle center to make the circle center coincide with the coordinate origin, and then to carry out coordinate conversion to make the starting point of the trajectory lie on the x-axis. Then FPGA calculates the phase by division. After phase processing, the phase information obtained is a sinusoidal signal that changes periodically with time. A specific numerical value will be obtained after sawtooth wave solution and an integration processing of a specific cycle length are performed on the obtained phase signal.

In view of the application environment of video signal processor in photoelectric signal processing system, this paper, with the aim to automatically eliminate or restore the system imaging interruption caused by single event locking of video signal processor, studies the single event locking protection technology of the photoelectric signal processing system, carries out embedded design and verification experiment of the fusion of the unlocking control circuit and the system circuit, and realizes the automatic unlocking control of the photoelectric signal processing system when single event locking occurs in video signal processor.

2.2 Theoretical research of heave compensation control system

The real-time signal processing system of non-equidistant two-way communication of photoelectric field consists of a laser, a signal acquisition module, a signal processing module and a database. The non-equidistant two-way communication signal of photoelectric field is output by laser, and then the real-time signal of non-equidistant two-way communication signal of photoelectric field is acquired by signal acquisition module. The signal processing module adopts the bidirectional output signal processing method of coherent detection to process the collected signal, thereby realizing the real-time signal processing of t non-equidistant two-way communication signal of photoelectric field. The processed signal enters in the database. The database can not only effectively store the related data generated by the system, but also provide the most powerful support for signal processing. One of the most important characteristics of the locking failure of the device is the loss of function of the locking device accompanied by a sudden large increase in operating current and maintenance of abnormality. By cutting off the power supply, the locking of the device can be effectively released, and the function of the device can be restored when the power is supplied again.

Communication power supply which plays an important role in the wind and photovoltaic integrated intelligent energy system provides power source for the base station. In the wind and photovoltaic complementary integrated energy source, to master the operating state of the communication power supply can ensure timely treatment when communication power supply failure occurs. Signal processing and analysis technology is the key technology to extract the operating state information of power supply. In the face of the rapid development of energy technology, the diversified demands of customers, and the continuous improvement and progress of energy acquisition technology, it is necessary to continuously improve the communication signal processing level and optimize the operation and layout of energy. We should make full use of internal and external resources to realize the complementary advantages of resources, create a favorable environment for the construction of energy market, and build an integrated energy service system with more mature technologies.

To guarantee the safe and reliable operation of the communication power supply, it is necessary to adopt a proper method to process the signal in the communication power supply, so as to ensure that problems can be found in time when abnormal operation of the communication power supply occurs, so that effective measures can be taken to solve the problems existing in the power supply and restore the normal operation of the communication power supply.

The active heave compensation control system is a compensation control system formed by moving posture control systems such as rolling, pitching and inclination control under the influence of sea waves. If the heaving movement speed of the replenishment ship is v_A and the heaving movement speed of the replenished ship is v_B, then the relative movement speed of the two is v_{BA}. If the replenishment speed during the operation of the crane is recorded as v_s and the speed of the load carried is recorded as v_M, then the actual speed of the ship is recorded as v'_{BM} during the actual compensation control, which can meet the requirements of the basic formula: $v_{BM}=v_M-v_B=v_S-v_A-v_B=v_S+v_{BA}$. The purpose of the replenishment system is to ensure that the speed of the main ship is the same relative to the ship being replenished when compensation is made.

Then the ship compensation control process is simplified to a two-dimensional control problem, the control angle is $\sin\theta=1$, and the correlation function composed of n control parameters is obtained as:

$$X(n)=\left[x_1(n),x_2(n),\cdots,x_N(n)\right]$$

$$A_1(\phi_1)=\begin{bmatrix}1\\ \exp\left(-j2\pi\frac{d}{\lambda}\cos\phi_1\right)\\ \vdots\\ \exp\left[-j2\pi(M-1)\frac{d}{\lambda}\cos\phi_1\right]\end{bmatrix}$$

where, (ϕ_1) is the compensation steering angle of the first control parameter.

A unified control matrix is established for the N compensation parameters, that is

$$A=\left[A_1,A_2,\cdots,A_N\right]$$
$$W=\left[W_1,W_2,\cdots,W_M\right]$$
$$y(t)=W^HAX^H=W^HU$$

where,

$$U=\left[u_0,u_1,\cdots,u_{M=1}\right]^H$$
$$IM_{F_j}=\frac{1}{2n}\sum_{i=1}^{2\pi}C_{ij}$$

Communication power supply plays an important role in the in the wind and photovoltaic integrated intelligent energy system. For example, the communication base station needs to use the communication power supply to provide power source for the base station. In the wind and photovoltaic complementary integrated system, to master the operating state of the communication power supply can ensure timely treatment when communication power supply failure occurs. Signal processing and analysis technology is the key technology to extract the operating state information of the communication power supply. In the face of the rapid development of energy technology, the diversified demands of customers, and the continuous progress in energy and Internet technology, it is necessary to continuously improve the communication signal processing level and optimize the operation and layout of energy system. We should make full use of internal and external resources to realize the complementary advantages of resources, create a favorable environment for the construction of energy market, and build an integrated energy service system with more mature technologies.

To guarantee the safe and reliable operation of the communication power supply, it is necessary to adopt a proper method to process the signal in the communication power supply, so as to ensure that the abnormal operation of the communication power supply can be found in time, so that effective measures can be taken to solve the problems existing in the communication power supply and restore its normal operation.

After the sensor detecting system detects the operation signal of the communication power supply system, it can feed back to the signal processing and control system, and upload the analysis result to the actuator system, completing corresponding operation and control. The above signal processing technology is helpful for the safe and stable operation of the integrated energy system, and it is of great significance to construct an integrated energy service system.

3. STUDY ON REAL-TIME SIGNAL PROCESSING OF NON-EQUIDISTANT TWO-WAY COMMUNICATION OF PHOTOELECTRIC FIELD

The signal acquisition module is composed of 18-bit sampling A/D chip, which has eight channels and can be up to 200KSPS, and can realize digital filtering and data integration ADC core, tracking amplifier and power supply. In order to keep the input of non-equidistant two-way communication signal of photoelectric field, a single 5V power supply is used to ensure the input of real-time signal. In addition, the non-equidistant two-way communication signal of photoelectric field received through the RESET port is transmitted to the CONVST-A and CONVST-B ports after the initial signal is converted by A/D. After the conversion is successful, the signal is sent from the BUSY port to CS for signal reading. Meanwhile, the signal data is sent to the signal processing module through the parallel port DB.

In the design process of the active heave compensation control system, attention should be paid to structural design and functional design unit.

In the actual design process, the operation principle of the control system shall be combined to ensure that the controller processing unit, the forward/backward channel and the external interface play their respective roles [7-9]. On the one hand, it is necessary to design the forward channel, integrate the power of inclination and acceleration sensors, and exert the advantages of rotary encoder and tension sensor, so as to ensure a certain adjustment effect.

What should be noted is that when the compensation control signal is detected, the working state of PID controller should meet the system requirements. On the other hand, it is necessary to design the control algorithm, integrate the PID control structure and the fuzzy control structure, so as to establish and perfect the fuzzy controlled object [10-12]. Besides, in the design of backward communication and man-machine interface, the realization of real-time monitoring should be taken as the fundamental purpose of system operation.

A set of compensation parameters for different control states is established:

$$D_t(s_t) = \{v_t | 0 \le v_t \le J - s_{t-1}\}$$

Thus, the corresponding transfer equation is obtained as follows:

$$s_{t-1} = s_t - v_t$$

Then establish the index evaluation function

$$U_{t,0} = U_{t,0}(s_t, v_t, s_{t-1}, \ldots, s_0)$$

Through this evaluation function, we can accurately determine whether the parameters of the compensation control meet the overall requirements of the system, and finally get the system equation as

$$\begin{aligned} U_{t,0}(s_t, v_t, s_{t-1}, \ldots, s_0) &= U_t(s_t, v_t(s_t)) + U_{t-1,0}(s_{t-1}, \ldots, s_0) \\ &= U_{it} + U_{t-1,0}(s_{t-1}, \ldots, s_0) \end{aligned}$$

Considering the discreteness of the above functions, we can get the following by recurrence criterion [13-15].

In order to improve the anti-interference ability, the mathematical model of maximum interference noise is established as

$$F_t(s_t) = \max\{U_{t,0}(s_t, v_t, s_{t-1}, \ldots, s_0)\}$$

Converted into:

$$F_t(s_t) = \max\{U_{it} + F_{t-1}(s_{t-1})\}$$

The above equation satisfies $F_0(s_0)=0$.

By solving the recurrence equations [16-18], a solution matrix can be formed, which contains all the parameters required for the compensation control positioning, namely

$$\{v_1(s_1), v_2(s_2), \ldots, v_n(s_n)\}$$

$$g(t) = V\exp\left(-\frac{t^2}{-2T^2}\right)\cos(W_c t)\#$$

In order to optimize the compensation control, a self-learning algorithm is used in this paper, which can learn and modify the matrix parameters in real time. Firstly, the state of the parameter at the time t is determined s_t, and then the correction value r_{t+1} that needs to be adjusted is determined according to different control requirements, and then the state change of the system is $s_t \rightarrow s_{t+1}$.

$$Q(s,a) = E\left[\sum_{k=0}^{\infty} \gamma^k r_{t+1+k}\right]$$

$$|y_{ij}| = (\sum a_{ij} \bullet b_{ij} + c_{ij}) \bullet d_{ij}$$

where, γ is a global factor ($0 \le \gamma \le 1$). The larger γ is, the stronger the compensation control ability of the system is.

The functional design of the active heave compensation control system includes:

First, effectively detect the ship trim and heaving posture.

Second, effectively control the speed of hydraulic motor.

Third, effectively establish a self-diagnosis report.

Fourth, effectively improve the heave compensation detection and drive system.

Due to the great randomness and intermittency of the output of wind power and photovoltaic power, their probability characteristics are very obvious, so the signal processing in the wind and photovoltaic integrated intelligent energy system can be conducted by means of probability calculation technology, so that signal processing is performed more efficiently and accurately. The probability calculation technology is very practical in the processing of probability events, which can reliably and accurately model the probability events, reduce the interference in the process of communication signal processing and improve the accuracy of signal processing. At the same time, the probability calculation technology owns more advantages than the traditional technology, such as reducing the signal processing time.

4. EXPERIMENTAL VERIFICATION AND ANALYSIS

The free space wave plate made of electrooptical material is the core component of polarization controller, which is mainly responsible for orientation. When the voltage changes, the orientation of the wave plate does not change while the delay changes. In order to obtain a new polarization state point, the free space wave plate rotates the polarized light to the desired polarization state point. The free space wave plate includes two compensation wave plates and two main control wave plates. The control algorithm can be used to control the polarization state of non-equidistant two-way communication initial signal of photoelectric field.

The laser transmits non-equidistant two-way communication signal light wave of photoelectric field, and the signal light wave is polarized by a polarization controller and a polarization beam splitter. On the basis of polarization decomposition, the real-time signal of non-equidistant two-way communication of photoelectric field is processed by coherent detection method. The photoelectric detector is an important part of the coherent detection receiver. The photoelectric conversion is realized by mixing the signal and two local oscillation beams and then transmitting them to the photoelectric detector. In the digital signal processor, frequency offset estimation, error compensation, phase recovery and the like can be implemented, and quadrature algorithm is used to compensate and recover the signal. The uplink optical carrier is loaded into the optical carrier through the wavelength reuse of the uplink local oscillator light and the uplink vector signal is fused into the optical carrier through the current modulator, and is transmitted to the detector by the optical fiber. Coherent detection in conducted on the received uplink signal light, and the decoded vector error analysis is performed by a digital signal processor.

The probability calculation method is applied to the detector and translator in the communication signal in the wind and photovoltaic complementary integrated intelligent energy system and meets the circuit processing requirements of the communication signal. In general, the value of the communication signal in the wind and photovoltaic complementary integrated intelligent energy system is relatively large. When applying the signal processing flow of Bayesian probability logic to process the communication signal in the wind and photovoltaic integrated intelligent energy system, we should first encode the communication signal by adopting the AND-OR INVERTER logical relationship. After discretization of the input communication signal, we can conduct logic analysis and finally output the corresponding continuous signal. The first received signal is generally analog quantity, so probability quantity can be used to represent the signal and then convert into discrete quantity again, thus realizing the application of the probability calculation method in communication signal processing.

A probability calculation system should include a sequence generator which converts signal into a probability calculation which can be converted into a random ratio sequence. The value to be converted is successively compared with N random numbers between 0 and 1 with a digital comparator to obtain the desired random sequence. N random numbers are derived from a linear feedback shift register, and the signal is implemented by an analog-to-digital converter from input to representation in binary form. For the wind power and photovoltaic power in the integrated intelligent energy system, how to coordinate and control the output when the wind power and photovoltaic power are connected to the energy is an important problem. We can analyze the power generation characteristics of wind power and photovoltaic power, and transmit the communication signal to the control center after processing, so we can make a good impact on the integrated energy system of wind power and photovoltaic power in advance.

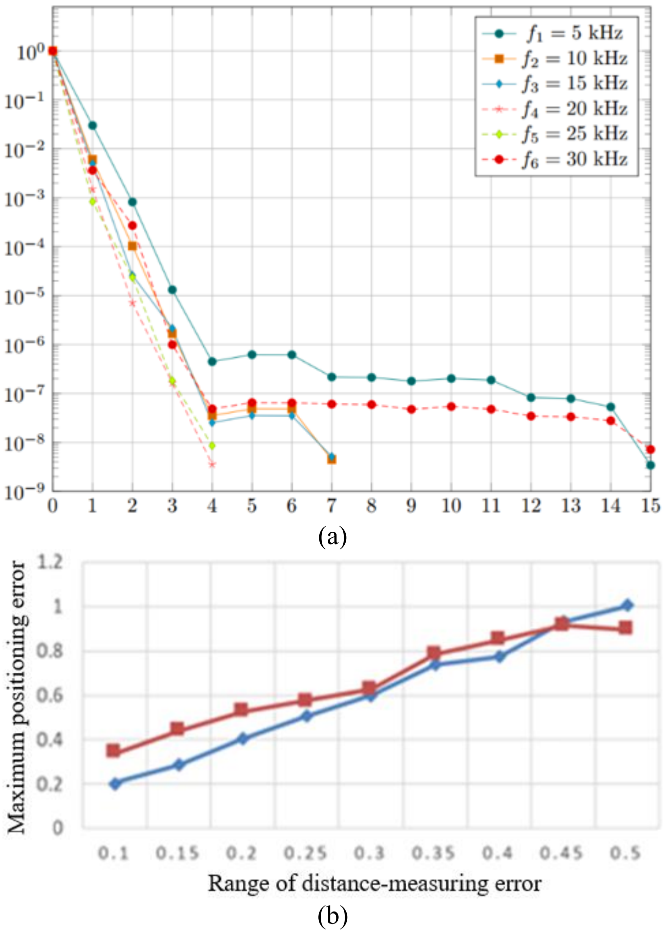

Figure 2. Compensation effect simulation chart

In the light of the single event locking phenomenon of the photoelectric signal processing system, the characteristic of the locking device itself and the interface characteristic and function of the photoelectric signal processing system, the single event locking protection idea for the video signal processing device is determined. The integrated embedded design of the unlocking control circuit and the photoelectric signal processing system circuit is realized, which can effectively identify the single locking event. If the device is locked, the device can be unlocked by cut off the power supply and repowering, the circuit can be reallocated, and the image processing function of the photoelectric signal processing system can be recovered. The system function recovery time is less than 5S.

By means of *Matlab* simulator, the design and analysis of each subunit are carried out.

Firstly, signal subsystem input module. A subsystem is created with *Simulink* to maintain parameter adjustment level and form the infrastructure.

Secondly, fuzzy control system module. *FuzzyLogicController* is integrated and attention is paid to the setting scope to ensure timely adjustment and processing [19, 20].

Thirdly, design of parameter subsystem. In the modeling process, the output parameters are modified to meet the compensation requirements of the system [21, 22].

The active compensation mechanism of the ship is established to truly exert the advantages of the system simulation analysis, so that the active compensation control of the ship can adapt to different flow disturbances. Figure 2(a) shows the compensation curves at different frequencies. The controller using the active compensation algorithm can improve the control effect, as shown in Figure 2(b).

5. CONCLUSION

In order to improve the real-time signal processing efficiency of non-equidistant two-way communication of photoelectric field, a real-time signal processing system for non-equidistant two-way communication of photoelectric field is studied. In the study, a real-time signal processing system of non-equidistant two-way communication of photoelectric field is composed of a laser, a signal acquisition module, a signal processing module and a database. Furthermore, the real-time signal processing of non-equidistant two-way communication of photoelectric field is realized by using coherent detection method. Finally, the result shows that the system has high robustness and good performance, which can realize signal processing.

In the light of the single event locking phenomenon of the photoelectric signal processing system, the characteristic of the locking device itself and the interface characteristic and function of the photoelectric signal processing system, the single event locking protection idea for the video signal processing device (AD9942) is determined. The function and index of the unlocking control circuit are analyzed and designed. The experimental results show that the unlocking control circuit can realize the integrated embedded design with the photoelectric signal processing system circuit and can effectively identify the single locking event. If the device is locked, the device can be unlocked by cut off the power supply and repowering, the circuit can be reallocated, and the image processing function of the photoelectric signal processing system can be recovered.

Probability calculation owns obvious application advantage in communication signal processing, with strong anti-interference, and the accuracy of the calculation result is very high. In the future, probability calculation is worth popularizing in the analysis and calculation of energy system [23, 24]. The instability in the communication signal circuit of the wind and photovoltaic integrated intelligent energy system will affect the inaccuracy of the communication signal processing result. By adopting the probability calculation method, the problems existing in the communication signal circuit are processed by probability mathematical method, and the communication signal can be reasonably extracted and processed. Regarding the trend of integrated energy services, China is now in an important moment of energy transformation, and environmental protection and energy security will become the driving force for the shift of energy strategy to diversification and cleanness [25]. At present, the integrated energy services mainly face the terminal system.

The feedback function of the ship active heave compensation system, on the basis of improving the control structure and system design level, should be improved to ensure that the high performance advantages of the system can be brought into play. On the premise of effective control of ships, the result of simulation analysis is integrated to promote the sustainable development of shipping industry.

Based on the study of the sensing property of FBG sensor network, this paper takes hybrid wavelength division/time division multiplexing sensor network with high-capacity FBG as the research object to study noise source, noise category and traditional noise reduction algorithm. This paper preprocesses sensing signal with the proposed LCEEWD-LWT method, which overcomes the shortcoming that the traditional signal processing method is not meticulous for high-frequency signal processing, but also avoids the problem that the signal processing time is too long. It has a good effect on the preprocessing of high-capacity FBG sensing signal.

This paper conducts a large number of researches in temperature sensing. In order to carry out multi-angle testing and research, it is planned to carry out experimental research on stress sensing, and to conduct signal repair research on the loss of signal in the process of FBG data acquisition.

REFERENCES

[1] Zeh, T. (2005). Optical fiber Bragg sensors - measurement systems and signal processing. Ph.D. dissertation, Technical University of Munich.

[2] Crockett, B., Cortés, L.R., Maram, R., Azaña, J. (2022). Optical signal denoising through temporal passive amplification. Optica, 9(1): 130-138. https://doi.org/10.1364/OPTICA.428727

[3] Zhou, J., Li, X.J., Zhang, W., Quan, Y.H. (2013). Hardware design of a universal radar signal processor. Electronic Science and Technology, 26(5): 91-94. https://doi.org/10.16180/j.cnki.issn1007-7820.2013.05.025

[4] Zhu, M.H. (2013). Optimization designs of SAR signal processing system. Measurement & Control Technology, 32(9): 147-150. https://doi.org/10.19708/j.ckjs.2013.09.040

[5] Patra, G.R., Mohapatra, S.K., Mohanty, M.N. (2022). Applications of deep learning algorithms in biomedical signal processing-pros and cons. International Journal of Biometrics, 14(1): 98-124. https://doi.org/10.1504/IJBM.2022.119560

[6] Jin, A.X., Niu, Y.L., Wang, X.N., Liu, L.X., Duan, C.D., Chen, W.X. (2015). Design and implementation of HY-2A satellite scatter meter signal processing onboard. Space Electronic Technology, 12(4): 27-29. http://dx.chinadoi.cn/10.3969/j.issn.1674-7135.2015.04.006

[7] Wang, G., Suo, Z.Y. (2015). design of insar real-time signal processing platform based on DSP+FPGA. Artificial Intelligence View, 2(5): 604-608. http://dx.chinadoi.cn/10.16453/j.issn.2095-8595.2015.05.017

[8] Chen, L.J., Tu, Y.Q., Liu, P., Shen, Y.L. (2015). Design of LFMCW radar ranging signal processing system based on DSP + FPGA. Transducer and Microsystem Technologies, 34(12): 94-96. http://dx.chinadoi.cn/10.13873/J.1000-9787(2015)12-0094-03

[9] Huang, Y., Hu, S., Ma, S., Luo, Q., Huang, D., Gao, Y., Shi, R. (2018). Constant envelope OFDM RadCom fusion system. EURASIP Journal on Wireless Communications and Networking, 2018(1): 104. https://doi.org/10.1186/s13638-018-1105-6

[10] Li, Y.X., Zhu, X.Y. (2022). Design and Testing of Cooperative Motion Controller for UAV-UGV System. Mechatronics and Intelligent Transportation Systems, 1(1): 12-23. https://doi.org/10.56578/mits010103

[11] Wei, X., Li, M., Mao, R., et al. (2022). An improved method of bunch-by-bunch beam position calculation in a heavy-ion synchrotron. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 1021: 165947. https://doi.org/10.1016/j.nima.2021.165947

[12] Jin, L.C., Hashim, A.A.A., Ahmad, S., Ghani, N.M.A. (2022). System Identification and Control of Automatic Car Pedal Pressing System. Journal of Intelligent Systems and Control, 1(1): 79-89. https://doi.org/10.56578/jisc010108

[13] Nesterov, Y. (2003). Introductory lectures on convex optimization: A basic course (Vol. 87). Springer Science & Business Media.

[14] Bell, G.R., Rincón, E., Akdoğan, E., Collins, S.R. (2021). Optogenetic control of receptors reveals distinct roles for actin-and Cdc42-dependent negative signals in chemotactic signal processing. Nature Communications, 12(1): 6148. https://doi.org/10.1038/s41467-021-26371-z

[15] Shen, T.A., Huang, S.Y., Chen, P., Chen, L.W. (2022). A novel CMF signal processing method based on notch filter and correlation method. Electronic Measurement Technology, 45(14): 140-144. http://dx.chinadoi.cn/10.19651/j.cnki.emt.2209142

[16] Janati, S., Mehdizadeh, S.A., Heydari, M. (2022). Designing, manufacturing, and evaluating the diagnostic system of carob moth in pomegranate fruit using digital signal processing. Computers and Electronics in Agriculture, 192: 106564. https://doi.org/10.1016/J.COMPAG.2021.106564

[17] Gao, Y.Z., Wang, J.M., Lei, Z.Y., Zhang, Y., Tao, C.Y. (2021). Mimic signal processing method for distributed opportunistic array radar. 43(11): 1-8. http://dx.chinadoi.cn/10.16592/j.cnki.1004-7859.2021.11.001

[18] Geng, Z.Q., Zhu, H.M., Li, X.M., Chen, Q.M., Yang, G.P. (2021). A review: Radar signal processing based on high performance computing. Electronic Science and Technology, 34(9): 1-6. http://dx.chinadoi.cn/10.16180/j.cnki.issn1007-7820.2021.09.001

[19] Luo, X.H., Zhang, B.F. (2011). Statistical analysis of literature on the radar signal processing research based on bibfiometrics. Cyber Security and Data Governance, 30(2): 1-4. http://dx.chinadoi.cn/10.3969/j.issn.1674-7720.2011.02.001

[20] Ebrahimzadeh, E., Asgarinejad, M., Saliminia, S., Ashoori, S., Seraji, M. (2021). Predicting clinical response to transcranial magnetic stimulation in major depression using time-frequency EEG signal processing. Biomedical Engineering: Applications, Basis and Communications, 33(6): 2150048. https://doi.org/10.4015/S1016237221500484

[21] Sheng, H., Qi, X. (2022). Application of new digital signal processing technology based on distributed cloud computing in electronic information engineering. Future Generation Computer Systems, 128: 443-450. https://doi.org/10.1016/J.FUTURE.2021.10.032

[22] Jiang, H., Li, D., Zhang, X., Ma, Z., Lu, T., Shao, X. (2021). Research on de-noising method of fiber grating multiplexing network based on LCEEMD-LWT. Optik, 247: 167997. https://doi.org/10.1016/j.ijleo.2021.167997

[23] Jiang, H., Zhang, X. M., Li, D., Zhao, Y., Zhang, Z. (2021). Multi-peak detection algorithm based on wavelength feature recognition in FBG sensor networks. Optical Engineering, 60(10): 106104. https://doi.org/10.1117/1.OE.60.10.106104

[24] Triana, C.A., Pastor, D., Varón, M. (2016). Enhancing the multiplexing capabilities of sensing networks using spectrally encoded fiber Bragg grating sensors. Journal of Lightwave Technology, 34(19): 4466-4472. https://doi.org/10.1109/JLT.2016.2537362

[25] Cheng, J., Yu, D., Yang, Y. (2006). Research on the intrinsic mode function (IMF) criterion in EMD method. Mechanical Systems and Signal Processing, 20(4): 817-824. https://doi.org/10.1016/j.ymssp.2005.09.011