Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Prospects on Future Instrumentation and Control (I&C) System based on Technologies of the Fourth Industrial Revolution

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1. Introduction

The fourth industrial revolution (4th IR) is about to affect our daily life. The 4th IR can be characterized as an extensive fusion of advanced technologies in different disciplines [1]. Massive progresses made in various disciplines would be integrated to generate totally new and unprecedented types of services. In this study, current advances in the 4th IR technologies are briefly presented and prospects on future applications of the 4th IR technologies to nuclear I&C are discussed.

2. Prospects on Future I&C

Attentions are primarily paid to technological advances in Internet of the Thing (IoT), big data analysis (BDA), artificial intelligence (AI), wearable and implantable devices (WID), robotics including autonomous operation and drone system, neuroscience, and augmented and virtual reality for Nuclear I&C systems in NPPs. Advances in IoT technologies enable data acquisition and processing from a lot of devices to be easier and faster. Big data analyses will be applied to figure out a set of meaningful information from the massive amount of data. AIs are applied when a machine mimics "cognitive" functions that humans associate with other human minds, such as "learning" and "problem solving" [2]. Nowadays advanced AIs such as ALPHAGO [3] and IBM WATSON [4] have shown incredible performance in a lot of cognitive activities. Wearable or implantable devices equipped with smart sensors facilitate applications of psychophysiological measurement techniques to NPP workers for human factors. Robotics including drone technologies has improved remarkably. Neuroscience is the scientific study of the nervous system and advanced technologies and measurement facilities help applications to human factors worldwide. Computer technologies to increase visibility of human have been largely evolved to applications of augmented and virtual realities. Augmented reality (AR) and virtual reality (VR) have been widely studied in nuclear fields including the OECD Halden project such as design, upgrade, and installation of SSCs (Systems, Structures, and Components) before actual execution, development of VR simulator, ACR design improvement, human factors verification and validation (V&V), operators training and ergonomics, studies to reduce radiation dose during operation, maintenance, refueling, nuclear waste treatment, and decommissioning, and safety staff training (e.g., police, fire department personnel, paramedics) and physical security during accidents including evacuation planning and contaminated area walkthrough [5].

2.1 Automation

Advanced systems including NPPs are being automated more and more, even though the extent of automation in NPPs is relatively less than other plant systems. NPPs would be fully automated someday in future. Several AI systems would be adopted simultaneously to satisfy the traditional requirements in nuclear I&C of redundancy, diversity, and independency for a fully automation NPP. Adaptive automation (AA) is a stage before the full automation which involves dynamic, real-time change in the degree of automation (DOA) in response to situational changes [6]. Change of automation level would be triggered by plant system condition and/or operator performance condition, which could be monitored, analyzed, evaluated and finally managed by integrating data from sensors of the plant system and psychophysiological data of operators. This integration would be effectively made with the IoT, BDA, WID, and AI. Data including not only plant systems data but also on-line and off-line maintenance data would be monitored with smart-sensor-based IoT applications, analyzed with big data analyses, and then managed by AI. Regarding the operator performance, if an operator shows poor or unacceptable performance, a level of automation should be shifted to another level to increase performance of the system including the automated system and human operators. A lot of psychophysiological measurement techniques including eye movement, EEG (electroencephalogram), EOG (electrooculogram), EMG (electromyogram), heart rate, skin temperature, GSR (galvanic skin resistance), facial expression, and body gesture have been being applied in human factors. Existing studies with these psychophysiological measurement techniques have learnt a lesson that multiple techniques should be used in a complementary way for real-field applications to overcome drawbacks coupled with respective techniques of the psychophysiological measurement [7].

2.2 Human Factors

Evaluation, analysis, and management for human factors in NPPs would be implemented in an integrated manner by AI systems. This kind of technological fusion of the 4th IR can be applied in several human factors areas in NPPs including operator condition monitoring for AA, operator performance evaluations, operator support system, worker job fitness evaluation, and insider threat prevention. Advanced technologies in psychophysiological measurements including eye tracking, EEG, ECG, EMG, GSR, voice, facial expression, and gesture can be integrated with WIDs. IoT, BDA, neuroscience, and AI should be effectively integrated to develop this kind of applications. Operator condition monitoring for AA has already been addressed in the previous section. The psychophysiological measurements have been effectively used to grade the level of operator performance such as task performance, situation awareness, and cognitive workload. Studies on operator performance in relation to HMI (human machine interface) design including V&V and HRA (human reliability analysis) will be remarkably advanced with the 4th IR technologies. Easier, faster, and more reliable way of acquiring and processing a variety of psychophysiological data based on IoT, BDA, and AI will facilitate simultaneous evaluation, analysis, and management of HMI and human error. Eye tracking data coupled with 3D (three dimensional) human motion measurements such as MVN BIOMECHTM [8] can be used to evaluate personnel tasks of operators. EEG, EOG, EMG, heart rate, skin temperature, and GSR as well as eye tracking data have been utilized to evaluate situation awareness and cognitive activity of operators in NPPs [9]. A lot of psychophysiological measurements have been used to evaluate worker job fitness. Emotion monitoring techniques using bio signals have been applied to enhance the safety in various fields and commercialized in some companies such as BMW, Toyota, GM, Samsung, etc. [10]. The techniques have been applied in the development of IoT technique and wearable device. Especially eye tracking data have been used to evaluate the worker job fitness in NPPs [11]. Operator support system will show remarkable advances by providing optimal operation of an NPP based on system and operators conditions aforementioned. Optimal procedures will be proposed and validated for the normal operations based on operational modes, and then timely feedback will be provided. On abnormal or emergency situation, appropriate procedures, work environment, and task sequence and timing of tasks will be coordinated to make best performance by analyzing and evaluating the operator condition as well as the system condition. Security is another most important pillar in NPPs as well as safety. Insider threat has been recognized one of significant threats in NPPs. Operator condition recognized from the psychophysiological measurements can be integrated with the studies on human emotions to find out potential insider threats to NPPs. Studies on emotion identified from facial expression and gesture shows remarkable progress to be applied and integrated into the operator condition to spot insider threat among people working in an NPP. Studies on facial expression and gesture have been widely applied in various industries. Especially detecting a liar or screening a lie has been studied a lot in criminal psychology. These kind of results from the criminal psychology can be effectively integrated with the operator condition recognized from the psychophysiological measurements to spot out potential insider threats in NPPs.

2.3 Advanced Maintenance Systems

Maintenance plays a significant role in terms of economics as well as safety of NPPs. Smart sensors equipped on IoT can provide all data related to operation, life, and performance of SSCs (systems, structures, and components). Big data obtained from IoT connections of NPP SSCs are analyzed and then AI based on the BDA can be applied to development of maintenance strategy and methods. Eventually reliability of SSCs can be increased and optimal management of inventory and reliability of SSCs can be accomplished on minimum costs.

2.4 Real-time Risk Assessment & Managements

Risk assessment has been recognized to be more and more important and especially risk management based on real-time risk assessment has been studies and conducted a lot to increase safety of NPPs. Real-time data obtained from IoT connections of NPP SSCs can be applied to big data analysis. NPP risk models are then updated with reliability data of NPP SSCs re-evaluated with the big data analysis. Best strategy or practice for best risk management is proposed and validated by an AI using the updated risk models and data and information from all other available sources such as technical specifications, cost-benefit analysis, and so on.

2.5 Interactive Accident Managements

Risk prevention and mitigation has been key ways of managing nuclear safety in abnormal situations in NPPs. If all SSCs equipped with smart sensors in a NPP are connected on IoT, highly reliable prognosis and diagnosis can be made from BDAs and AIs processing all available data including accident-related data and meteorological data from on-site surveillance drone. Emergency preparedness such as evacuation, sheltering, dose-dependent relocation, and KI ingestion can be best supported by AIs based on data from the drone. Also direct de-contamination and coolant supply might be provided by advanced drone systems. In the Fukushima accident, SBO (station blackout) was the initiating event and the massive damage to road sides due to tsunamis made it worse, because mobile EDGs (emergency diesel generator) or water could not be supplied to spots in need. Advance robots can be effectively used to connect mobile EDG or water supply during such kind of severe accidents as the Fukushima accident. Already unmanned multiped walking robots which can access spots even though loads are somewhat broken have been developed and commercialized in various area. If IoT-based multiple smart sensors, which monitor the status of a NPP site ground, are developed, best access road and countermeasures can be proposed by AIs coupled with BDA based on the site ground data obtained through the IoT connection given that access roads broken.

3. Concluding Remarks

Current advances in the 4th IR technologies have been remarkable and interests on these technologies have been more and more increasing. A lot of discussions also have been made to advance further and apply the 4th IR technologies to almost all industries worldwide. In the meantime, the state-of-the-art and prospects on future applications of the 4th IR technologies to nuclear I&C have been studied and discussed in this paper. Even though this paper cannot deal with all possible applications of the 4th IR technologies to nuclear I&C, the readers of this paper are expected to have a guideline to their future R&Ds related to the 4th IR technologies.

REFERENCES

[1] S. Klaus, The Fourth Industrial Revolution, New York: Crown Publishing Group, ISBN 9781524758875, 2017.
[2] S. J. Russell, P. Norvig, Artificial Intelligence: A Modern Approach (3rd ed.), Upper Saddle River, New Jersey: Prentice Hall. ISBN 0-13-604259-7, 2009.
[3] https://deepmind.com/research/alphago/
[4] https://www.ibm.com/watson/
[5] Silva, A.P. Legey, and A.C. Mol, "Review study of virtual reality techniques used at nuclear issues with emphasis on Brazilian research", Annals of Nuclear Energy, Vol. 87, Part 2, pp. 192-197, 2016.
[6] J. O'Hara, J. Higgins, D. Ki, and S. Fleger "Effects of Adaptive Automation on Operator-system Performance", 10th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies (NPIC&HMIT 2017), San Francisco, CA, USA, pp. 19-25, 2017.
[7] A.F. Kramer and T. Weber, "Application of Psychophysiology to Human Factors", In J.T. Cacioppo (ed), Handbook of Psychophysiology, Cambridge, U.K.: Cambridge Univ. Press, pp. 794–814, 2000.
[8] https://www.xsens.com/products/mvn-biomech/
[9] J.S. Ha, P.H. Seong, HUPESS: Human Performance Evaluation Support System. In: Seong, P.H. (eds.): Reliability and Risk Issues in Large Scale Safety-critical Digital Control Systems. Springer-Verlag London Limited, 2009.
[10] ABI Research, '세계의 운전자 모니터링 시스템 시장', 137121, 2014.
[11] M.K. Choi, J.S. Ha, P.H. Seong, "Suggestion of the Eye-tracking system based Fitness-for-duty Evaluation Methodology in Nuclear Power Plants", Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, Octorber 26-27, 2017.