IoT-based Smart and Complex Systems: A Guest Editorial Report

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THE Industrial Revolution starting from about 1760 and ending at around 1840 has been viewed as the first Industrial Revolution. It features with the replacement of human and animal muscle power with steam and mechanical power. Human income per capita had taken 800 years to double by the early 1800's. Since 1760, the first Industrial Revolution spent only about 150 years to increase human income per capita by thirteen-fold. While historians are still debating what the second Industrial Revolution is, many believe that it is Internet Revolution. It started in about 60 years ago. It features the applications of computing, communications, and networking and information storage in every aspect of human life. It offers even much faster growth of human income per capita and drastically promoted industrial productivity.

What is the next Industrial Revolution? Different researchers and industrial engineers tend to offer different answers. For example, Rifkin presents in [1] his answer as "Energy Internet" where people produce their own green energy in their homes, offices, and factories, and share it with each other just as information is shared via Internet. Manufacturing engineers would believe that 3-D printing and digital manufacturing as the next industrial revolution, through which people can conceive, design, manufacture and recycle their own one-of-a-kind products [2]. For computer scientists and engineers, artificial intelligence, big data analysis, cloud computing, and fog/edge computing are their likely choices as the third Industrial Revolution [3]−[7]. Evans and Annunziata of General Electric Company answered this question by coining a name "Industrial Internet" [8], which is popularly called Internet of Things (IoT) [9]. We agree with it because the next technological wave must move from today's Internet connecting mostly people to people via smart terminals like computers and smart phones to tomorrow's IoT linking everything in the world. As a result, IoT-based smart systems promise to offer the opportunities for another even sharper productivity increase than the prior industrial revolutions for not only human beings but also every machine and everything in the world. There is no doubt that such IoT-based systems become more and more popular as well as pose numerous modeling, design, analysis and control challenges. The systems are able to intelligently respond to their environment and offer value-added services to their clients. Their discrete-event nature and hybrid modeling, control, scheduling, simulation and security management pose a deluge of theoretically significant and practically meaningful issues to researchers in various fields. They often require interdisciplinary efforts and mathematical modeling and optimization approaches to move this field forward.

This special issue has collected 18 original contributions reporting the latest advances in IoT-based smart and complex systems. They present the latest research results on the state-of-the-art complex system modeling and analysis methods, and recent new findings obtained by using systems engineering methodologies to the design and evaluation of IoT-based Smart and Complex Systems.

Wireless sensor networks (WSN) are an important branch of IoT. Several papers of the issue deal with their design, analysis and applications. Duan *et al.* present a methodology to design a high-performance and reliable WSN based on a software defined network in a changing industrial environment. In the context of industrial IoT, we face WSN node failures caused by energy depletion and hardware malfunctions. The industrial environment can be very harsh and can adversely impact wireless channel transmission, thus leading to serious network reliability problems and increasing network management cost. With the help of software defined networks, the authors invented a framework called the improved software defined wireless sensor network. For a large scale heterogeneous network, they successfully solve the problem of network management and smooth merging of a WSN into industrial IoT. Their work ensures high network coverage with high network performance by addressing addresses node failure issues as caused by energy depletion.

One of the primary functions of WSN is to produce various data. Efficient data collection issues are addressed by Song and Li in their paper "Data Gathering in Wireless Sensor Networks via Regular Low Density Parity Check Matrix". To guarantee the lifetime of WSNs, the data gathering via random sensing is often used. Yet such randomness and WSN node density

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result in difficulty of implementations, high computation complexity and large storage spaces in practical WSN deployment. Deterministic sparse sensing matrices are sometimes desired, but their deployment cannot ensure high performance of WSN. The authors innovatively construct a class of deterministic sparse sensing matrices with statistical versions of restricted isometry property via regular low density parity check matrices. They can thus achieve the same measurement performance as the dense measurements can, thereby reducing energy consumption of WSNs.

Securing IoT has been an important issue. Intrusion detection has been a primary defense technique to network security. The next paper "An Intrusion Detection Algorithm for Wireless Networks Based on ASDL" by Zhu *et al.* presents a novel temporal logic language called attack signature description language (ASDL) and ASDL-based model checking algorithm. They can well describe attack signatures, and design the ASDL programs to create an audit log. Their case studies and simulations show that their algorithms can identify such challenging attacks as coordinated chop-chop attacks in wireless networks.

The paper "SVM-DT-Based Adaptive and Collaborative Intrusion Detection" " by Teng *et al.* gives a self-adaptive collaboration intrusion detection method based on the Environments - classes, agents, roles, groups, and objects (E-CARGO) model. The authors design the objects, roles, agents, and groups by using decision trees and support vector machines (SVMs) in their method. They then utilize a well-known dataset to verify the effectiveness of the method. Their experimental results demonstrate its feasibility and higher detection precision rate and recall rate than the method that uses a set of single type support vector machines.

Radio frequency identification (RFID) technology has been playing a key role in identifying an IoT object and has widely applied in manufacturing, warehouses, ports, stores and logistics. The paper "Capture-aware Bayesian RFID Tag Estimate for Large-scale Identification" by Wu *et al.* discusses passive RFID tag anti-collision issues. In a dynamic framed slotted Aloha algorithm, a frame length requires dynamical adjustment to achieve higher identification efficiency. Such adjustment is not only related to the number of tags, but also to the occurrence probability of capture effects. When estimating both the number of tags and the probability of capture effect under large-scale RFID tag identification, the existing algorithms fail to provide accurate estimates since the number of tags would be much larger than an initial frame length. To address this thorny issue, the authors invent a novel algorithm, called capture-aware Bayesian estimate, which adopts Bayesian rules to perform accurate estimates. Numerical results show that the proposed algorithm can well handle large-scale RFID tag identification problems with higher estimation accuracy and efficiency than the existing algorithms.

How can we apply the RFID technology to manufacturing systems? Ding and Jiang's paper "RFID-based Production Data Analysis in an IoT-enabled Smart Job-shop" presents an excellent answer to this question. While RFID technology brings convenience to production control and transparency, it also generates increasing data that are discrete, uncorrelated, and hard-to-use. To utilize the generated data of systems, the authors propose an innovative RFID-based production data analysis method for production control in IoT-enabled smart job-shops. Based on the physical configuration and operation logic of IoT-enabled smart job-shop production, they construct an RFID-based production data model to formalize and correlate the heterogeneous production data. Then, they propose an event-driven RFID-based production data analysis method to construct the RFID events and judge the process command execution. Consequently, they are able to excavate hidden information and knowledge from the historical production data to help managers and production engineers improve the performance of manufacturing systems.

Complex engineering systems requires sophisticated modeling and production scheduling. The paper "Collision-free Scheduling of Multi-bridge Machining Systems: A Colored Traveling Salesman Problem-based Approach" by Li *et al.* has address the scheduling issue faced by the optimal operations of multi-bridge machining systems. These systems contain multiple bridge machines working in parallel and their workspaces partially overlap. The authors innovatively express their scheduling problems as a serial-colored travelling salesman problem in which each salesman has some exclusive cities and some shared cities with its neighbor(s). They develop a greedy algorithm that selects a neighboring city satisfying proximity. The algorithm allows a salesman to select randomly its shared cities and runs accordingly many times. It can thus be used to solve job scheduling problems for multi-bridge machining systems. Subsequently, a collision-free scheduling method is proposed to address both job scheduling and collision resolution issues. Their algorithm can select a job for an individual machine such that no time overlaps exist between it and the job sequence of the neighboring machine in the overlapping workspace; and remove such a time overlap only when it is inevitable. Their results have been successfully applied to a large triple-bridge waterjet cutting system.

Multi-agent systems and technologies are important in realizing IoT-based complex systems. The next several papers deal with their modeling and control issues. In the paper "The Formation Control of Multi-agent Systems on a Circle", Wang *et al.* investigate the formation control problem for a class of multi-agent systems moving on a circle whose topology is a cyclic graph. They focus on the agents with single and double-integrator kinematics. Several control protocols are proposed to keep a uniformly-spaced formation and ensure the stability of the formation. Their simulations results show that their designed control protocols can work very well to achieve the desired formation control of their concerned multi-agent systems.

The next paper "Gini Coefficient-based Task Allocation for Multi-robot Systems With Limited Energy Resources" by Wu *et al.* deals with the energy-constrained robots working in such dangerous environments as earthquake rescue and exploration of wild areas. If the energy resources of some robots are consumed too fast, the future tasks requiring their coalition are to be at high risk. The authors thus develop a novel task allocation method based on Gini coefficient to make full use of limited energy resources of a multi-robot system to maximize their capability in handling tasks. They incorporate the market-based allocation mechanism into their Gini coefficient-based method to formulate a hybrid method. It can flexibly maximize the number of completed tasks or minimize resource consumption according to the application needs.

In the third paper of multi-agent systems, Yang and Yue investigate a consensus tracking problem of networked multi-agent systems in a non-affine pure-feedback form. They propose to build up a distributed adaptive tracking consensus control scheme recursively by using a backstepping method, graph theory, neural networks and dynamic surface control technology. Its core advantages include avoiding the complexity problem as the degree of individual agents grows and thus decreasing the computational burden drastically. Second, it poses no requirement for prior knowledge about system parameters of individual agents and uncertain dynamics. Finally, it guarantees the consensus errors to be cooperatively semi-globally uniformly ultimately bounded.

In the fourth paper of multi-agent systems, Wang *et al.* studied guaranteed cost consensus analysis and design problems for high-dimensional multi-agent systems with time-varying delays. They introduce guaranteed cost control into the consensus problems for such complex multi-agent systems and define a cost function based on state errors among neighboring agents and control inputs of all the agents. They then establish the sufficient conditions for guaranteed cost consensus and consensualization by using a state space decomposition approach and linear matrix inequality. They also derive a guaranteed cost upper bound of the cost function and validate their results through numerical simulations.

The last paper about multi-agent systems is entitled “Cyber-Physical-Social System Between a Humanoid Robot and a Virtual Human Through a Shared Platform for Adaptive Agent Ecology” written by Rahman. This work focuses on two artificial agents, i.e., a humanoid robot and virtual human, which are integrated in the form of a cyber-physical-social system (CPSS) through a shared communication platform to create a social ecology. In the ecology, two agents assist each other to perform a real-world task, e.g., finding a hidden object, to benefit humans. The author derives a robot-virtual human bilateral trust model and a real-time trust measurement method. The role of taking initiative in their collaboration can be switched between them by following a finite state machine model, and thus mixed initiative collaboration is likely. Their performance can be evaluated through a cyber-physical-social system. The results prove the effectiveness of the real-world ecology between artificial agents of heterogeneous realities through a shared platform based on trust-triggered mixed-initiatives. This work makes an important progress in the development of adaptive social ecology comprising intelligent agents of heterogeneous realities to assist humans in various tasks through their collaboration.

Understanding people’s emotions through natural language is a challenging issue for intelligent. The major difficulty is caused by the lack of basic knowledge in emotion expressions with respect to a variety of real world contexts. The paper “Exploring Latent Semantic Information for Textual Emotion Recognition in Blog Articles” by Kang *et al.* aims to address it. The authors pioneered in a Bayesian inference method to explore the latent semantic dimensions as contextual information in natural language and to learn the knowledge of emotion expressions based on these semantic dimensions. Their method can synchronously infer the latent semantic dimensions as topics in words and predicts the emotion labels in both word-level and document-level texts. The Bayesian inference results enable one to visualize the connection between words and emotions with respect to different semantic dimensions. By further incorporating a corpus-level hierarchy in the document emotion distribution assumption, they are able to balance the document emotion recognition results and achieve even better word and document emotion predictions. Their experimental results based on a well-developed Chinese emotion corpus prove their proposed method’s higher accuracy and better robustness in the word-level and the document-level emotion predictions than several state-of-the-art emotion prediction algorithms.

Many identical or similar robots can form a swarm. Traditionally these robots all have the same or invariable controller during their entire life time and thus fail to handle time-varying complex environments. In the paper “Time-varying Algorithm for Swarm Robotics” contributed by Hou *et al.* propose the use of variable controllers in order to adapt to such changing environments. Their proposed algorithm takes time as one of the independent variables such that the controller is no longer fixed over the time; instead they can be changed over time, which brings more choices for a swarm robot system. They have applied different control strategies to the same flock during the time, and are able to obtain interesting and useful control effects for the swarm of robots.

The paper “Active Queue Management Exploiting the Rate Information in TCP-IP Networks” by Boudi and Loudini gives a new mechanism called explicit rate notification that can be well used in end-to-end communications in Internet. The proposed scheme encodes in the header of transmission control protocol (TCP) packets information about the sending rate and the round trip time of the flows. This new available information to the intermediate nodes (routers) is used to improve fairness, increase utilization, decrease the number of drops, and minimize queueing delays. Thus, it induces a better management of the queue. Through the comparison of the proposed scheme with several existing schemes, e.g., an explicit congestion notification scheme shows its effectiveness. It has excellent potential to be used in Internet as well as IoT.

The paper “Distributed Containment Control of Networked Nonlinear Second-order Systems with Unknown Parameters” by Ma *et al.* presents the containment control problem for nonlinear second-order systems with unknown parameters and multiple stationary/dynamic leaders who can be robots or agents. The interactions between these leaders and their followers are described through directed graphs. This work introduces both stationary leaders (a regulation case) and dynamic leaders (a dynamic tracking case) based protocols. It computes the unique final states of all the followers given the initial values of leaders and a directed graph. In the regulation case, all the followers converge into the convex hull spanned by the leaders, while in the dynamic tracking case, not only the positions of the followers converge into the convex hull but also the velocities of the followers converge into the velocity convex hull of the leaders. Their theoretically solid results are illustrated through several numerical simulations.

Mi and Li's paper "Event-triggered MPC Design for Distributed Systems with Network Communications" deals with the communication problem in a distributed system in which each wireless network node has the limited battery power and redundant transmission among nodes is allowed. The authors pioneered in an event-triggered model predictive control strategy to reduce the unnecessary communication while guaranteeing the desired system performance. They derive a triggering condition based on the Lyapunov stability for a linear discrete time-invariant system. They further reduce the communications amount by enforcing a triggering condition only when the Lyapunov function exceeds its value at the last triggered time.

The last paper of this special issue is "Detecting Data-flow Errors Based on Petri Nets with Data Operations" contributed by Xiang *et al.*. In order to guarantee the correctness of business processes, not only control-flow errors but also data-flow errors should be well handled. The control-flow errors include deadlock, livelock, and soundness, which have been well addressed. Data-flow errors may take place during such data operations as reading, writing and deletion. Their detection is lacking. This work defines Petri nets with data operations that can well model the data operations. Based on them, the authors formally define data-flow errors. They then construct a reachability graph with data operations for each net model, and propose a method to reduce the originally large reachability graph. Based on the reduced graph, they can find data-flow errors rapidly. They use a case study to illustrate the applications of their Petri net model and data-flow error detection methods.

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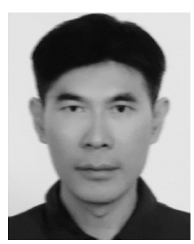

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