International Workshop on Smart City: Control & Automation Perspectives

Workshop Report

Ming Ge Tariq Samad Anke Xue
11/2/2013

Contents

1 Motivation and Objectives

This report is a synthesis of presentations and discussions in the International Workshop on Smart City: Control and Automation Perspectives, held at Zhejiang Hotel in Hangzhou, China, on August 27 – 29, 2013. The workshop was supported by Hangzhou Dianzi University, IEEE Control Systems Society Outreach Fund, Zhejiang Research Center for Smart City, Honeywell International, and Zhejiang Province Government.

The idea of organizing this workshop was triggered by observations that more and more cities in China and elsewhere have realized the importance of utilizing advanced technology and solutions to address problems of urbanization. These problems include resource consumption, environmental degradation, security, and congestion. At the same time, as a result of advances in information technologies and infrastructure investments, platforms for developing and deploying advanced applications — analytics, modeling, optimization, and closing the loop on technical systems in cities — are being implemented.

This workshop aimed to establish a platform for triangular parties - Government, Industry and Academe – to exchange ideas, discuss challenges and put forward possible solutions in the hope that a more interactive community/forum could be developed to define and address the problems associated with the smart city. Leading researchers, industry experts, and government agency representatives convened to discuss a wide spectrum of problems, address challenges and explore opportunities for smart city from control and automation perspectives. Renowned academicians and professors from USA, Europe and Asia were invited to deliver plenary talks on various topics such as advanced control and optimization of future goods transportation, energy and water network synthesis from global/localcontrol perspectives, large scale distributed model-predictive control for distribution network control and optimization, and cloud manufacturing that defines a new pattern and approach for smart manufacturing.

This report sums up key findings, thoughts, and suggestions arising from the workshop for cross-institutional collaborations between industry, academe, and government. This report is available on the web sites of the IEEE Control Systems Society Outreach Fund and the official website for the Workshop (http://smartcity.hdu.edu.cn). The latter includes presentations from the workshop as well.

2 Structure

We believe this workshop was the first of this kind within the control systems research community to bring academic, industry and government experts together to discuss the issues and challenges, share the experience and lessons, frame the problems, and explore the opportunities about smart city. To concentrate on the key items and topics within a short period of time, the organizers structured the workshop in two layers of interaction: In the first two days presentations and discussions mostly centered around specific themes followed by two panel sessions to further explore the depth and breadth of smart city research and applications. In the last half-day a round table discussion session was arranged for invited government officials, industry representatives and academy professors to talk about the critical issues and challenges and to brainstorm possible solutions from a more practical perspective.

All sessions were very well attended and a number of interesting and stimulating questions were raised by the participants. These inter-disciplinary and cross-boundary discussions helped to define and frame problems for control and automation experts to further investigate. Both invited speakers and participants expressed a strong desire in attending or organizing similar sessions in the future.

3 Key Topics

The concept of smart city (or smarter city) has been promoted extensively to various domains. To achieve a better focus on control and automation perspectives, for the purposes of this workshop the smart city is defined as a holistic system that consists of numerous interconnected subsystems in the areas of transportation, energy, water system, security, logistics, healthcare, etc. As has been demonstrated in the broad application of industrial and academic research results, control system could be employed in many aspects of the smart city, from scheduling algorithms in energy distribution of smart grids, to the predictive control for city water management systems, to automation with feedback in road traffic management systems, and to sensor networks for applications such as environmental monitoring and security. More applications of control systems for the smarter city will emerge if the control research community could better understand challenges and opportunities posed by cities through the interaction with city governments and industry players.

In this workshop, participants and invited speakers discussed the application of control technology to various areas of smart city. In particular, the following topics were explored:

1) Smart logistics/transportation;
2) Smart water;
3) Smart energy/grid;
4) Smart manufacturing;
5) Smart security.

4 Summaries of Invited Presentations

The workshop featured twelve presentations delivered by prominent researchers with expertise in a broad array of smart city related topics from technology-specific issues to a macro-level overview of smart city relevant challenges. Summaries of these presentations appear below.

Smart city, from a macro level perspective, can be seen as a complex socio-technical system with potential risks that needs to be predicted and managed effectively. Prof. Venkat Venkatasubramanian, the Co-Director of the Center for the Management of Systemic Risk, Columbia University, U.S., presented an overview of challenges facing the city and described the ongoing research in his center for the management of systemic risk. He argued that a better city needs not only an “IQ” (intelligence quotient) aspect, which emphasizes efficiency, reliability/robustness, optimization, and sustainability with advanced technology in computers, communication, and controls domains, but also an “EQ” (emotional quotient) aspect that goes beyond pure engineering and focuses on human elements and social elements such as happiness, desire, interactivity, etc. A novel control-theoretic framework was presented that unifies the social and the technical components of a complex system to better model, control, and manage systemic risk in a smart city.

Prof. Venkatasubramanian pointed out that one needs to go beyond analyzing system failures as independent one-off accidents, and examine them in the broader perspective of the potential fragility of all complex systems. Modern technological advances are creating an increasing number of complex engineered systems, processes, and products, which pose considerable challenges in ensuring their proper design, analysis, control, safety, and management for successful operation over their life cycles. It is their scale, nonlinearities, inter-connectedness, and interactions with humans and the environment that can make these systems-of-systems fragile, when the cumulative effects of multiple abnormalities can propagate in numerous ways to cause systemic failures. In particular, the nonlinear interactions among a large number of inter-dependent components, and the environment, can lead to “emergent” behavior – i.e. the behavior of the whole is more than the sum of its parts, which can be difficult to anticipate and control.

Prof. Venkatasubramanian concluded that one needs to study all these disasters from a common systems engineering perspective, so that one can thoroughly understand the commonalities as well as the differences, in order to better design and manage such systems in the future. Further, such studies need to be carried out in concert with public policy and regulatory experts (and governmental agencies) so that all the scientific and engineering lessons get translated into effective policies and regulations.

Prof. Fei-Yue Wang, Director of the State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, proposed the “ACP based parallel control and management approach” – essentially a data-driven approach for modeling, analysis, and decision making - as a new mechanism for conducting operations of smart city as a complex system that deeply involves intricate issues of both engineering and social dimensions. Prof. Wang presented an overview of the ACP approach’s background, concepts, methods, and major issues. Case studies he illustrated and analyzed in transportation and production systems indicated that the ACP approach is effective and efficient in networked complex systems like smarty city and its association with the emerging technologies in cloud computing, social computing and cyber-physical-social systems has made it even more powerful.

Also treating the smart city as a complex system, Prof. Shinji Hara of the University of Tokyo, Japan, sought to address this complexity from another angle. He proposed the idea of "Glocal Control”, which employs local actions of measurement and control to serve a global purpose, and its technical foundation with applications to multiple aspects of the smart city. A unified framework for hierarchical large-scale networked dynamical systems was introduced, where the nature of multiple resolutions in time/space/frequency/level depending on the hierarchical layers is a key issue. The theory underpinning the framework includes linear time-invariant (LTI) systems with generalized frequency variable, low rank inter-layer interactions (aggregation and distribution), and multi-resolution fits with different layers. After showing fundamental results on stability, robust stability, and hierarchical decentralized control in this framework, Prof. Shinji Hara presented two practical applications of glocal control: the management of energy network systems consisting of a variety of energy resources by hierarchical decentralized control and the design of a control network structure for realizing a so called "Smart Water City," proposed by the Japanese Instrumentation and Control Society, SICE. Prof. Hara also touched upon on the importance of taking human and thus social factors into consideration in the process of building a harmonized smart city.

To create a smart, sustainable and safe city, Prof. Dr. Hock Beng Lim, the Director of the Intelligent Systems Center, Nanyang Technological University, Singapore, described the major research and technical challenges for realizing the potential of smart cities. He presented a holistic R&D framework to support the development of technologies and applications. He highlighted his team's recent efforts in the development and deployment of city-scale systems for the application domains of weather and environmental monitoring, water distribution network monitoring, transportation activity surveys, smart and energy efficient buildings, etc., in Singapore.

Location based service (LBS) has seen widespread use in smart city applications with the technology breakthroughs in cloud computing and global position systems. Prof. Deyi Li, Academician of Chinese Academy of Engineering, presented LBS's applications in smart driving and smart transportation. Prof. Li argued that LBS serves as the basis for many smart city applications and the improvement of LBS such as accuracy of the position system and computing capability will be central to the success of its applications. Prof. Li also demonstrated his team's research results in smart vehicles by the use of LBS and a hybrid navigation strategy.

To illustrate the latest advance in smart traffic applications, Dr. Carlos Canudas-de-Wit, the Director of research at CNRS, GIPSA-Lab, Grenoble, France, shared his Grenoble Traffic Lab initiative that aims to set up a real-time traffic data center (platform) in order to collect traffic road infrastructure information in real-time with minimum latency and fast sampling periods. Dr. Carlos Canudas-de-Wit first reviewed main conservation models which are used as a basis to design physical-oriented forecasting and control algorithms. In particular he underlined fundamental properties like downstream/upstream controllability and observability of such models, and presented a new network set-up for analysis. Then he presented advances in traffic forecasting using graph-constrained macroscopic models which substantially reduce the number of possible affine dynamics of the system and preserve the number of vehicles in the network. This model is used to recover the state of the traffic network and precisely localize the eventual congestion front. The last part of his talk centered around issues on density balancing control, where the objective is to design the homogeneous distribution of density on the freeway using the input flows as decision variables. His study showed that effective balancing of traffic flow requires the coordination of ramp metering and variable speed limit control, and he outlined the minimum feedback structure to reach such balancing. Despite these promising results, challenges for future research remain, such as the processing of large amounts of data (both online and offline), mixed scales (macro and micro), uncertainty in models and existing knowledge, multiple decision-making levels and complexities of the interplay with society and people.

Prof. Karl Henrik Johansson, the Director of the KTH ACCESS Linnaeus Centre, Royal Institute of Technology, Sweden, also discussed the challenges and issues relevant to transportation, more specifically, goods transportation. Goods transportation is of substantial importance for a smart city and is increasing dramatically as the world develops. A recent study published by the International Transport Forum revealed that goods transportation accounts for about 23% of CO2 emissions from all fossil fuel combustion and 15% of all greenhouse gas emissions. Despite the influence the transportation system has on our energy consumption and the environment, goods transportation is mainly done by individual long haulage trucks with no real-time coordination. Tests have shown that individual platooning trucks traveling close together can save about 10% of their fuel consumption as a result of reduced air drag.

Prof. Johansson also explained in detail how modern Information and Communication Technologies (ICT) can support a future goods transportation system where trucks in a fleet are coordinated to travel together in vehicle platoons. Control and estimation challenges on various level of this transportation system were highlighted and feasible solutions were presented. An innovative coherent system architecture was introduced utilizing vehicle-to-vehicle and vehicle-to-infrastructure communication to enable receding horizon optimal control of individual trucks as well as platoons and fleets of platoons. Preliminary results from a large-scale evaluation performed on the highway road network in Northern Europe has demonstrated benefits and feasibility in practice utilizing the platooning strategy with the proposed control architecture for large scale optimization. Prof. Johansson concluded by presenting some data from joint work with KTH and Scania, a Swedish truck manufacturer, demonstrating more fuel-efficient goods transportation with platooning control and other truck-coordination strategies.

The theme of smart transportation was elaborated further by Prof. Raja Sengupta of the University of California, Berkeley, U.S, who discussed the broader leverage of ICT to smarten the cities of the future. The field of Intelligent Transportation Systems (ITS), now well established in standards, trade associations, and academia, represent 30 years of ICT impact on the supply-side. Examples include ramp metering, integrated corridor management, smart buses, and collision warning systems, all of which exploit ICT to squeeze more out of the smart city’s endowment of physical infrastructure. Prof. Sengupta revealed that ICT have an equally revolutionary impact on the demand side and presented his perspective on the Nextgen Intelligent Transportation initiative that utilizes ICT to help adapt citizen behavior to city transportation services for the benefit of both city and citizen. He discussed the new field of Behavior Change Technology founded on the control sciences and ICT. The influence of

ICT on citizen behavior was explored through the lens of his team's pioneering work on real-time transit information and smart parking (see modechoice.net and automatic.com).

Growing cities are characterized by a tightly woven infrastructure where transportation and energy networks are diversifying and merging. For example, electrified transportation creates unique mobility options and constraints while simultaneously imposing new energy demands and storage opportunities. Maximizing the efficiency of such interconnected systems requires strong fundamental science for modeling, estimation, and control. To address this, Prof. Scott Moura of the University of California, Berkeley, U.S, talked about his work on thermostatically controlled loads (TCLs) in the built environment. TCLs comprise nearly 50% of electricity consumption in the U.S. His research centers on exploiting the inherent flexibility of TCLs to achieve city or region-wide benefits via demand response. Aggregations of large-scale distributions of thermal spaces can be elegantly modeled by coupled partial differential equations (PDEs). This modeling framework enables one to perform analysis, estimation, and control design using recently developed techniques for PDE systems. By leveraging state-estimation techniques, a minimal sensing/communication infrastructure can be implemented to monitor and control a diverse population of TCLs. Prof. Moura argued that the framework is also applicable, given statistical data on mobility patterns, for managing electric vehicle-to-grid (V2G) interactions which is one of the hottest themes of smart grid/energy. He concluded his presentation with an overview of open questions and future research plans in creating intelligent energy and mobility infrastructures for smart cities.

Along with smart transportation and smart building, water distribution has also long been considered a pivotal component of a smart city. Dr. Vladimir Havlena, Senior Fellow at Honeywell Laboratory, Prague, Czech Republic, provided an overview of distributed optimization methods that are at the core of large scale model predictive control technology and its application to municipal water management system. Water supply and distribution problems are formulated in a concise control and optimization framework so that the real-time solution could be achieved through dual decomposition using multi-parametric programming with significantly accelerated convergence and reduced computational burden. Performance and benefits from distributed MPC were illustrated by application to the control and energy efficiency optimization of the transport layer of a large city water management system in Barcelona.

In addition to the topics discussed above, Prof. Bohu Li, Academician of Chinese Academy of Engineering, presented his recent research results in cloud manufacturing that is a new pattern and approach for manufacturing in smart cities. Cloud manufacturing is a novel, networked and intelligent manufacturing model that is service-oriented, knowledge based, production effective and energy efficient. In this model, state-of-the-art technologies such as informatized manufacturing, cloud computing, Internet of Things, semantic Web, and high-performance computing are seamlessly integrated in order to provide secure, reliable, and high quality on-demand services at low prices for those involved in the whole manufacturing lifecycle. As an important part of cloud manufacturing, Prof.Li also introduced cloud simulation technology based on the COSIM-CSP platform that has been applied in the design of a multidisciplinary virtual prototype of a flight vehicle. This lays the foundation for further research into cloud manufacturing.

5 Challenges

Through the intensive discussions and lively interactions over the two-and-a-half days of the workshop, participants achieved a better understanding of smart cities and related opportunities for research and application. With the rapid urbanization and advances in information, communication and control technology, there is huge potential to develop technology, products and solutions to address the socio-technical challenges in order to build a smarter city. The interaction between academe, industry and government agency made it possible to underscore issues which are not familiar to the researchers with academic controls background but are strongly felt as highly critical in industry and government in order to address the customer needs. Challenges and open issues that were raised and discussed for the most part fell into four categories:

- Government's Role. A city is a very complex system so that effecting changes and improvements requires all stakeholders to pull together and make united efforts. The city/provincial government (usually the city mayor or governor) is required to lead the efforts and facilitate the collaborations between different departments and agencies. An example that repeatedly was taken by the government officials and industry representatives in the workshop is the data sharing in the implementation of smart highway in one of the richest provinces in China. For economic and political reasons, the highway data was separately collected and maintained in at least 3 departments (highway police bureau, highway investment group, and transportation department). Without the coordination of the governor, it would be difficult to modernize the province's highway information system and therefore advanced traffic control and optimization algorithms could not be deployed and implemented. This top-leadership-project strategy works sometimes but in reality it would be much too time-consuming for the top leaders to get involved in all sorts of smart-city projects. Therefore it is essential for the government to define its role in a more effective way, introducing legislation, policy and regulation to foster cooperation across stakeholders and bridge silos in operations and information.

- Control Framework. Control and automation technology have been broadly used in many aspects of the smart city. However, a coherent and unified control system architecture tailored for smart city has not yet been developed in spite of the new ICT technology emerging in a seemingly endless stream. The intricacy of the smart city is such that controls researchers will need to structure the problems on multiple dimensions. A balanced framework has to be built that encompasses systems from different perspectives (macro and micro, centralized and decentralized, unified and hierarchic).

- Sociotechnical Problem. The fundamental element of the city is the human being. In addition to the physical form of city infrastructure – the underlying structure that supports our city -- "non-physical" infrastructure that consists of social, political, economic and cultural support systems has to be considered in tackling technical challenges facing the smart city. Designing control strategies or developing optimization algorithms for human-in-the-loop systems is a daunting task. Social science, industry psychology, and human centered systems theory will help a lot in defining and addressing the sociotechnical problems systematically.

- Cross-domain collaboration. The complexity of the smart city requires inter-disciplinary and cross-institutional collaborations between industry, academe, and government. While industry has been promoting diverse "smart city" products and solutions, these are often developed for immediate needs and business opportunities. Academe has been by and large focusing on basic and applied research endeavoring to address the city problems but with little understanding of the "voice of the customer". In addition, the influence of government has been underrated—in most cities government plays an essential role in advancing policies and plans for urban development. This workshop served to bridge this gap and we hope there will be more similar actions in the future.

Despite—and because of—the challenges and open issues outlined above, participants all agreed that this is the right time to address smart city problems from a controls perspective, with advances in areas such as sensing, mobility, and information technologies providing enablers for advanced algorithms for Big Data mining, location-based services and apps, monitoring, estimation, control, and optimization.

6 Future Work

While control and automation technologies have seen an increasing number of applications to smart city, there is still a lot of work to be done to address the open issues and challenges described in this report. A few recommendations for future work are as follows:

- Benchmark problems. A constraint on current research is that academy lacks an in-depth understanding of customer needs. An effective solution to this limitation is the framing of typical benchmark problems abstracted from industrial applications. The benchmark problems should represent the most common challenges encountered in real applications. It is recommended that these problems be co-formulated by both industry and academy experts.

- Pilot programs. The best way to verify and validate the new technology and solutions is their deployment in pilot programs before undertaking large-scale applications. Identification of a few pilot programs that involve technologies from different disciplines (controls, computers, communications, etc) would strengthen the smart city related research and cultivate inter-disciplinary and cross-institutional collaboration.

- Workshops and forums. Workshops, seminars and forums are highly recommended to be held regularly for the exchange of ideas, experience and lessons among industrial and academic partners as well as government representatives. Also special issues on smart city in top-rated journals would increase the awareness of the importance of the smart city and strengthen the collaboration between industry and academe.

7 Summary

In summary, the workshop highlighted up-to-date progress, key challenges, and opportunities related to smart city from control and automation perspectives. Follow up actions are recommended to further the research and applications. Forums and platforms to foster the interplay of academy, industry and government are strongly encouraged in particular to establish a thorough understanding of smart city needs. We hope this workshop will be remembered as the first step on the journey of modernizing the city to make it smarter and more effective.

Appendix I: Workshop Agenda

Date/Time	Items	Speakers/Host/Facilitator	Topic
27-Aug-13			
0830 – 0900	Opening Ceremony	Tariq Samad/Anke Xue/Ming Ge	
0900 – 0940	Plenary Talk (1)	Prof.Venkat Venkatasubramanian	Managing Systemic Risk in Complex Socio-Technical Systems
0940 – 1020	Plenary Talk (2)	Prof.Deyi Li	Location Service: A Fundamental Issue for Building up Smart City
1020 – 1035	Break		
1035 – 1115	Plenary Talk (3)	Dr.Carlos Canudas-de-Wit	Forecasting and control of traffic systems: a network perspective
1115 – 1155	Plenary Talk (4)	Prof. Raja Sengupta	Adapting the Citizen to the City: NextGen Intelligent Transportation
1155 – 1235	Plenary Talk (5)	Prof. Karl Henrik Johansson	Control and Optimization of Future Goods Transportation
1235 – 1330	Lunch		
1330 – 1410	Plenary Talk (6)	Prof.Bohu Li	Cloud Manufacturing - A New Model and Approach for Smart Manufacturing
1410 – 1450	Plenary Talk (7)	Prof. Anke Xue	Applied Research for Smart City: A Pragmatic Approach
1450 – 1505	Break		
1505 – 1545	Smarty City Project	Prof.Chen Qi	Samrt Urban Water Management
1545 – 1715	Panel Session (1)	Tariq Samad	Smart Transportation/Traffic
1715 – 1800	Reception		
1800 – 2000	Dinner		

28-Aug-13

0830 – 0910	Plenary Talk (8)	Dr.Vladimir Havlena	Large scale distributed MPC for distribution network control and optimization
0910 – 0950	Plenary Talk (9)	Prof.Hock Beng Lim	Towards Smart, Sustainable and Safe Cities
0950 – 1005	Break		
1005 – 1045	Plenary Talk (10)	Prof.Fei-Yue Wang	Parallel Control and Management for Smart Cites: An ACP Approach
1045 – 1125	Plenary Talk (11)	Prof.Shinji Hara	Energy and Water Network Synthesis from the View Point of Glocal Control
1125 – 1205	Plenary Talk (12)	Prof.Scott Moura	Modeling and Estimation of Demand Responsive Loads
1205 – 1300	Lunch		
1300 – 1530	Contributed Papers	Prof.Xiaodong Zhao/Prof.Song Zheng	
1530 – 1545	Break		
1545 – 1715	Panel Session	Ming Ge	Smart Water/Building/Energy/Grid
1715 – 1730	Closing Ceremony	Tariq Samad	
1800 – 2000	Dinner		

29-Aug-13 **(Invited People)**

0830 – 1000	Round-Table Discussion: Smart City Needs and Solutions
1000 – 1015	Break
1015 – 1145	Round-Table Discussion: Smart City Needs and Solutions
1145 – 1200	Closing Remarks

Appendix II: Invited Speakers

Prof. Venkat Venkatasubramanian, Co-Director of Center for the Management of Systemic Risk, Columbia University, U.S

Prof. De-Yi Li, Academician of Chinese Academy of Engineering, Beijing University of Posts and Telecommunications, China

Dr. Carlos Canudas-de-Wit, Director of research at CNRS, GIPSA-Lab, Grenoble, France

Prof. Karl Henrik Johansson, the Director of the KTH ACCESS Linnaeus Centre, Royal Institute of Technology, Sweden

Prof.Bo-Hu Li, Academician of Chinese Academy of Engineering, Beijing University of Aeronautics & Astronautics, China

Prof. Raja Sengupta, University of California, Berkeley, U.S

Prof.Fei-Yue Wang, Institute of Automation, Chinese Academy of Science, China

Prof. Shinji Hara, University of Tokyo, Japan

Prof. Scott Moura, University of California, Berkeley, U.S

Dr. Vladimir Havlena, Honeywell Laboratory Prague, Czech

Prof. Hock Beng Lim, Director of Intelligent Systems Center, Nanyang Technological University, Singapore

Prof.Chen Qi, Department of Computer Science, Zhejiang University, China