Situation, Activity and Goal Awareness in Cyber-physical Human-Machine Systems

RECENT advances in sensing technologies, the Internet of Things, pervasive computing, smart environments have transformed traditional embedded ICT systems into an ecosystem of interconnected and collaborating smart objects, devices, embedded systems and most importantly humans. Such systems, often referred to as cyber-physical systems (CPS), are usually human user-driven or user-centered, and are aimed at providing people and businesses with a wide range of innovative applications and services, *e.g.*, making smarter, more intelligent, more energy-efficient and more comfortable transport systems, cars, factories, hospitals, offices, homes, cities and personal devices. For example, a “Smart Home” can monitor and analyze the daily activities of its inhabitants, usually the elderly or individuals with disabilities, so that personalized context-aware assistance can be provided. A “Smart City” can monitor, manage and potentially control all basic city functionalities such as transport, energy supply and waste collection, at a higher level of automation by collecting and harnessing sensor data across a large geographic expanse.

In order to respond in real-time to an individual user’s specific needs in dynamic and complex situations, and to support ergonomics and user-friendliness through consideration of human factors such as privacy, dignity and behavior characteristics, cyber-physical human-machine systems need to be aware of the physical environment and human participant behavior. This awareness enables effective and fast feedback loops between sensing and actuation, possibly with cognitive and learning capabilities adapting to participant preferences, capabilities and the modality of human-machine interaction as well as dynamic situations. At the moment, vigorous research on cyber-physical human-machine systems and their applications has been undertaken in various national, regional and international research initiatives and programs. These include the smart home for supporting active and healthy aging, and smart cities to enhance performance and wellbeing, to reduce costs and resource consumption, and to engage more effectively and actively with citizens. A whole raft of heterogeneous computing technologies providing fragments of the necessary functionality, *e.g.*, sensor networks, data processing and activity recognition algorithms, has been developed. Nevertheless, to support the core features of this new breed of smart cyber-physical applications with context-awareness, personalization and adaptation, computational agents, devices and the overall human-machine systems need to be designed

for user activity and goal awareness as well as responsiveness to state changes.

The collection, modeling, representation and interpretation of the states, events and behaviors from humans to both physical and software agents/devices situated in a cyber-physical integrated environment need to be carried out in a formal systematic way and at a high level of abstraction. Such an approach can facilitate data fusion and joint interpretation based on multiple dimensions of observations (*e.g.*, environment context, human physical activities and mental or system states) as well as longitudinal pattern recognition. Over the past decade, the modeling, representation, interpretation and usage of sensor observations have shifted from low-level raw observation data and direct/hardwired usage, data aggregation and fusion, to high-level formal context modeling and context-based computing. It is envisioned that this trend will continue towards a further higher level of abstraction, allowing situation, activity and goal modeling, representation and inference. The resulting technologies will thus enable and support user-centered functionality, ergonomics and usability in the next generation of smart cyber-physical applications.

Though the awareness of situation, activity and goals by computational agents and/or devices plays a critical role in human-machine systems, there is currently a lack of publication and dissemination dedicated to the research activities and results of this niche area. This special issue is intended for researchers and practitioners from relevant research communities. This includes researchers from artificial intelligence (AI) with expertise in formal modeling, representation and inference on situations, activities and goals; researchers from ubiquitous computing and embedded systems with expertise in context-aware computing; and application developers or users with expertise and experience in user requirements, system implementation and evaluation. For researchers from the AI community, this special issue will highlight application opportunities and technological challenges. For researchers from cyber-physical systems and smart environments, this special issue will provide a solid theoretical foundation and enabling techniques for realizing novel goal-based situation-aware cyber-physical applications from formal goal, activity and situation modeling, representation and inference. The special issue also serves to motivate application scenarios from various domains including smart homes, intelligent meeting rooms and environmental monitoring. For solution developers and providers of specific application domains, this special issue will provide an opportunity to convey needs and requirements,

as well as obtain first-hand information on the latest technologies, prototypes, and application exemplars.

This special issue consists of ten high-quality research papers selected from a large number of submissions (80+), each going through at least two rounds of strict peer reviews and significant consolidation. They are listed in the Appendix and will be referred to by using item numbers in the remainder of this editorial. These papers represent the latest advances and development of research in the general context of situation, activity and goal awareness for smart human-machine systems. The research topics covered in this special issue are wide-ranging, including context modelling and inference for smart environments [item 1) and 2) in the Appendix], localization [item 3)], behavior mining and activity recognition [item 4) and 10)], social interaction analysis based on online social networks [item 5)], goal and intention modelling and inference [item 6)], social event mining and mobile crowd sensing [item 7) and 8)], and behavior-based privacy [item 9)]. The application areas involved are diverse, including assistive living in smart environments [item 1), 2) and 6)], workplace wellbeing [item 4)], indoor localization [item 3)], social media analysis [item 5)], crowd-sourced big data analysis [item 7) and 8)], privacy [item 9)] and business decision support [item 10)]. Details for each item are briefly described below.

Item 1) in the Appendix aims to build contextual models for new “smart” environments by reusing as much learned knowledge as possible from an existing environment. To this end, the authors propose a feature-based knowledge transfer framework for cross-environment activity recognition towards smart home applications. The framework makes use of transfer learning, which relaxes the constraints requiring model training and testing datasets to be highly similar in distribution. Experimental results show that this framework can successfully help extract and transfer knowledge between two different smart home environments. Models trained via the proposed framework can even outperform non-transfer-learning models by up to 8% in accuracy. Finally, the flexibility of the proposed framework allows its use as a test-bed for evaluating different methods and models in order to improve service quality of human-centric context-aware applications.

Item 2) in the Appendix aims to improve the efficacy, acceptance, adaptability and overall performance of human-machine systems and human-system interaction applications by developing a context-based approach. The study defines a general human model that leads to principles and algorithms allowing more natural and effective interaction between humans and artificial agents. In addition, it presents a new information model and specifications for context-aware interaction and decision support that can be integrated in cyber-physical human-machine system architectures. By integrating context and interaction information models, the decision-making component behaves as a supervision process for controlling interaction. The approach was implemented and tested targeting an application in the domain of active and assisted living.

Item 3) in the Appendix aims to address the sample impoverishment phenomenon in particle filter-based approaches to localization. The study proposes a novel nonlinear filtering method that combines a particle filter with a finite impulse response filter, dubbed as the composite particle / finite impulse response filter (CPFF) framework, in order to accomplish accurate and reliable localization. The CPFF framework uses the particle filter as the main filter in normal situations. When a particle filter failure occurs, the finite impulse response filter is used to recover the particle filter from failures. To detect particle filter failures, this paper developed a new decision-making algorithm. The CPFF framework was applied to indoor human localization using a wireless sensor network. Results demonstrated that the CPFF is accurate and reliable under conditions in which the pure particle filter typically exhibits degraded accuracy or failures.

Item 4) in the Appendix investigates loss of productivity due to workplaces injuries, aiming to provide a valuable set of services for both workers and administrators towards a healthier, and therefore, more effective workplace. It presents the design, implementation and evaluation of a novel computer-vision based human-centred activity tracking system that helps increase worker compliance with best safe practices. The authors develop a set of mechanisms that enable non-intrusive privacy-aware selective tracking of consented workers in the presence of people that should not be tracked. These include a single sign-on worker identification mechanism and a method that provides real-time detection of non-compliant activities. The proposed system is evaluated in a usability study using inexpensive programmable depth sensors, wearable devices, and smart phones. Results have shown that the system can track the activities of consented workers using the depth sensors, alert them discreetly on detection of noncompliant activities, and produce cumulative reports on their performance.

Item 5) in the Appendix investigates whether or not human social behavior expressed through an Online Social Network (OSN) can provide unique insight into user behavior recognition. It focuses on identifying and generating a set of unique features, called Social Behavioral (SB) features, from an individual’s social interactions using an OSN. Specifically, this research developed a set of SB features from online social interactions of 241 Twitter users and proposed a framework to utilize these features for automated user recognition. Results from extensive experimentation demonstrated high recognition performance as well as distinctiveness of the proposed SB features. The most striking finding was that only 10 recent Tweets are enough to recognize 58% of users in the database. The recognition rate dramatically increased to 93% when 60 Tweets were used as a probe set. Experimental results also demonstrated stability of the proposed SB feature set over time and ability to recognize both frequent and infrequent OSN users.

Item 6) in the Appendix presents an intelligent agent architecture and intention reasoning mechanism that offers a paradigm shift for creating smart home based assisted living. Rather than trying to infer an inhabitant’s activities from low-

level sensor data, the proposed approach is intended to monitor and recognise an inhabitant's intention from which context-aware assistance will be provided. The study developed both conceptual and computational goal, belief and intention models, and intention reasoning algorithms. The devised approach was incorporated in an intelligent agent architecture and evaluated in three scenarios. Each scenario was intended to test and assess the performance of the developed methods in different use cases, covering intention recognition mechanisms, assistance provisioning in a simulated smart home environment over a period of 3 months. Initial results revealed the approach to be promising, thus providing a potential solution for issues related to privacy, reusability, applicability, and scalability.

Item 7) in the Appendix aims to address sparse data and event concurrency issues in using urban events as bases for detecting and understanding irregular crowd movements and social activities. For this purpose, the authors propose a tensor co-factorization based data fusion framework for fine-grained urban event detection and characterization leveraging crowd mobility data and social activity data. The framework utilises a non-negative tensor co-factorization approach to decompose a crowd mobility tensor into several basic patterns, with the help of an auxiliary social activity tensor. Based on the decomposed basic patterns, a multivariate outlier detection method is developed to identify irregularities. By aggregating these detected irregularities the framework can detect and characterize the associated urban events. The performance of the framework is evaluated using real-world urban movement data from two different sources in two cities, and results have shown that by fusing the two types of urban movement data, the developed method achieves fine-grained urban event detection and characterization in both cities, and consistently outperforms the baselines.

Item 8) in the Appendix proposes ActiveCrowd - a worker selection framework for multi-task mobile crowd sensing environments. The study addresses the problem of multi-task worker selection under two situations: worker selection based on worker intentional movement for time-sensitive tasks and unintentional movement for delay-tolerant tasks. For time-sensitive tasks, workers are required to move to the task venue intentionally and the goal is to minimize the total distance moved. For delay-tolerant tasks, workers whose route is predicted to pass by the task venues are selected, and the goal is to minimize the total number of workers. Two greedy-enhanced genetic algorithms are proposed to solve these problems. Experiments verify that the proposed algorithms outperform baseline methods under different experiment settings including different scales of task sets, dynamic availability of workers and varied task distributions.

Item 9) in the Appendix describes a continuous and non-invasive user authentication system for wearable glasses, named GlassGuard, which is aimed to address the privacy issue in the use of smart glasses. GlassGuard continuously monitors user touch gestures and voice commands. To discriminate the owner and an impostor, Glassguard develops behavioral biometrics from 6 types of touch gestures (single-

tap, swipe forward, swipe backward, swipe down, two-finger swipe forward, and two-finger swipe backward) and voice commands, which are all available during normal user interactions. It employs a mechanism adapted from Threshold Random Walking to make a decision based on multiple user events only when it is confident. With data collected from 32 users on Google Glass, the study shows that GlassGuard achieves a 99% detection rate and 0.5% false alarm rate after 3.5 user events (on average), when all types of user events are available with equal probability. Under five typical usage scenarios, the system has a detection rate above 93% and a false alarm rate below 3% after less than 5 user events.

Item 10) in the Appendix aims to detect customer behavior patterns by mining ski resort lift usage data with the ultimate purpose of improving products and services offered by ski resorts. The study exploits descriptive data analysis for mining spatial and temporal patterns from ski lift entrance data. This includes a dataset of approximately 1.2 million recorded ski lift transportations, collected through RFID scanners during one skiing season. Cluster analysis was performed on 10 subsamples and the obtained clusters were cross-validated. Temporal clustering revealed that skier patterns differ according to time of maximal performance and length of stay in the ski lift transportation system. Spatial clustering revealed that it is reasonable to have as many clusters as ski lifts in a ski resort, since skiers tend to choose a dominant ski lift during a skier-day. The findings offer the potential for evidence-based ski resort decision support and management.

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APPENDIX RELATED WORK

- 1) Y.T. Chiang, C.H. Lu and J.Y. Hsu, "A Feature-based Knowledge Transfer Framework for Cross-environment Activity Recognition towards Smart Home Applications", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 2) J. Quintas, P. Menezes and J. Dias, "Information Model and Architecture Specification for Context Awareness Interaction Decision Support in Cyber-physical Human-Machine Systems", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 3) J.M. Pak, C.K. Ahn, Y.S. Shmaliy, P. Shi and M.T. Lim, "Accurate and Reliable Human Localization Using Composite Particle/FIR Filtering", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
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- 6) J. Rafferty, C. Nugent, J. Liu and L. Chen, "From Activity Recognition to Intention Recognition for Assisted Living within Smart Homes", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 7) L. Chen, J. Jakubowicz, D. Yang, D. Zhang and G. Pan, "Fine-Grained Urban Event Detection and Characterization Based on Tensor Co-Factorization", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 8) B. Guo, Y. Liu, W. Wu, Z. Yu and Q. Han, "ActiveCrowd: A Framework for Optimized Multi-Task Allocation in Mobile Crowdsensing Systems", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 9) G. Peng, G. Zhou, D.T. Nguyen, X. Qi, Q. Yang and S. Wang, "Continuous Authentication with Touch Behavioral Biometrics and Voice on Wearable Glasses", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.
- 10) B. Delibašić, P. Marković, P. Delias and Z. Obradović, "Mining skier transportation patterns from ski resort lift usage data", IEEE Transaction on Human-Machine Systems, vol.47, no.3, May 2017.

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