Guest Editorial Behavior Understanding and Developmental Robotics

Abstract—**The scientific, technological, and application challenges that arise from the mutual interaction of developmental robotics and computational human behavior understanding give rise to two different perspectives. Robots need to be capable to learn dynamically and incrementally how to interpret, and thus understand multimodal human behavior, which means behavior analysis can be performed for developmental robotics. On the other hand, behavior analysis can also be performed through developmental robotics, since developmental social robots can offer stimulating opportunities for improving scientific understanding of human behavior, and especially to allow a deeper analysis of the semantics and structure of human behavior. The contributions to the Special Issue explore these two perspectives.**

Index Terms—**Activity recognition, affective computing, attention, developmental learning, human behavior understanding, learning by demonstration, nonverbal communication.**

I. The Scope of this Special Issue

IN ORDER to act in a useful, relevant, and socially acceptable manner, robots will need to understand the behavior of humans at various levels of abstractions, at various time scales, and in the particular context of human–robot interactions. Robots need to be capable to learn dynamically and incrementally how to interpret, and thus understand multimodal human behavior. This includes for example learning the meaning of new linguistic constructs used by a human, learning to interpret the emotional state of particular users from paralinguistic or nonverbal behavior, characterizing properties of the interaction or learning to guess the intention, and potentially the structure of goals of a human based on its overt behavior

Furthermore, robots need in particular to be capable of learning new tasks through interaction with humans, for example using imitation learning or learning by demonstration. This heavily involves the capacity for learning how to decode teaching behavior, including linguistic and nonlinguistic cues, feedback and guidance provided by humans, as well as inferring reusable primitives in human behavior.

While some of the existing techniques of multimodal behavior analysis and modeling can be readily reused for robots, novel scientific and technological challenges arise when one aims to achieve human behavior understanding in the context of natural and life-long human–robot interaction. The first purpose of this Special Issue is to explore these challenges.

Our second purpose is to understand how behavior analysis can be achieved through developmental robotics. Developmental social robots can offer stimulating opportunities for improving scientific understanding of human behavior, and especially to allow a deeper analysis of the semantics and structure of human behavior. Humans tend to interpret the meaning and the structure of other's behaviors in terms of their own action repertoire, which acts as a strong helping prior for this complex inference problem. Since robots are also embodied and have an action repertoire, this can be used as an experimental and theoretical tool to investigate human behavior, and in particular, the development and change of behavior over time.

Digital Object Identifier 10.1109/TAMD.2014.2328731

II. Contribution to the Special Issue

This Special Issue incorporates six papers, two of which extend work presented in the Third International Workshop on Human Behavior Understanding [1]. We briefly summarize their highlights here.

Nonverbal signals play a very prominent role in human–human communication [2], [3], especially to coordinate joint actions and for the dance-like precision in the timing of interactions. But what happens if one of the communicating humans is replaced by a robot? **Alessandra Sciutti**, **Laura Patanè**, **Francesco Nori**, and **Giulio Sandini**, in their paper entitled "Understanding Object Weight from Human and Humanoid Lifting Actions," make a humanoid robot produce an informative set of nonverbal signals to communicate to a human partner the weight of an object in an implicit manner. They show that it is not enough that the robot chooses the optimum action (here correctly lifting a weight), but should perform it in a way to allow the humans to modify their own coordinated actions. Subsequently, a simple modification in robot action planning can produce a significant impact on the efficiency of the human–robot interaction.

The developmental trajectory of motor actions in humans contains a number of skills that are acquired in parallel, including gaze control, body orientation, reaching, and grasping behaviors. In "From Saccades to Grasping: A Model of Coordinated Reaching Through Simulated Development on a Humanoid Robot," **James Law**, **Patricia Shaw**, **Mark Lee**, and **Michael Sheldon** implement these skills on an iCub robot, and show that by mimicking a child's learning trajectory, it is possible to develop hand/eye coordination on complex kinematics rapidly. An interesting observation made by the authors is that motor babbling need not be random, but can relate learned actions to new exploration patterns, in a manner not unlike free play, which balances goal-oriented exploration and social guidance [4].

Social interactions are important sources of learning for children, but also form the complex backdrop of adult behavior. Recent work in computer analysis of human behavior focuses on complex and contextualized social interactions, as opposed to scenarios of a single person performing a single activity [5], [6]. One of the basic requirements of social interaction is the establishment of joint attention between the interacting parties. For natural human–robot interaction, realtime approaches that implement attentional mechanisms in robots would be essential. **João Filipe Ferreira** and **Jorge Dias** provide an in-depth assessment of this field in their paper "Attentional Mechanisms for Socially Interactive Robots–A Survey." They point out that robots also offer a possibility to study the underlying processes of attention in a detailed fashion and in complex settings, and thereby allow cognitive scientists powerful computational and physical platforms to test their theories of attention. Subsequently, research on attention demonstrates perfectly the two perspectives of behavior analysis for and through developmental robotics. The paper also shows that attention is primarily tackled in the visual domain in the field. There is a lot of room for novel approaches based on audio and multimodal information.

It is well-known that the human brain contains cross-modal and multimodal sensory integration from very basic, neuronal levels onwards [7]. In their paper "The MEI Robot: Towards Using Motherese to Develop Multimodal Emotional Intelligence," **Angelica Lim** and **Hiroshi G. Okuno** implement a developmental robot called MEI that can generalize emotional analysis across modalities, and correctly guess the emotional category of human gait after just being trained on the voice modality. In order to achieve this, a number of perceptual metafeatures are derived and matched from each modality: speed, intensity, irregularity, and extent, respectively. Lim and Okuno describe the semantic concepts covered by these four features in different domains like voice, gesture, and music, and postulate that during development, a joint perceptual space would be a simplified and intuitive explanation for learning to represent emotional expressions across all domains simultaneously.

Flexible and adaptive representations are essential for learning human behavior. **Alexandros Andre Chaaraoui** and **Francisco Flórez-Revuelta** propose to adapt a recent computer vision approach to action recognition in their paper "Adaptive Human Action Recognition with an Evolving Bag of Key Poses" by enhancing it with dynamic model update, and evolutionary parameter optimization. Constant change in the model parameters helps the system to adapt easily to new action classes, or new interaction partners.

In humans, as opposed to typical computer-based systems, recognition of actions is tied to reproduction of actions, so that improvements in one are reflected in the other to some degree. In their paper "Humanoid Tactile Gesture Production Using a Hierarchical SOM-based Encoding," **Georgios Pierris** and **Torbjørn S. Dahl** describe a perception–action system where a robot learns a hierarchical self-organized map (SOM) based representation for a demonstrated action, and reproduces the action while compensating for perturbations. This approach builds on Cohen's constructivist learning architecture (CLA), which is a model of learning that reproduces several effects from theories of infant cognitive development [8].

Taken together, these contributions exemplify schemes inspired by human development and behavior to improve robot behavior, as well as provide robotic systems on which cognitive theories and their predictions can be tested.

ALBERT ALI SALAH, *Guest Editor*
Boğaziçi University
Department of Computer Engineering
Istanbul, 34342 Turkey

PIERRE-YVES OUDEYER, *Guest Editor*
ENSTA ParisTech
Palaiseau, 91762 France

ÇETIN MERIÇLI, *Guest Editor*
Carnegie Mellon University
National Robotics Engineering Center, Robotics Institute,
Pittsburgh, PA 15213 USA

JAVIER RUIZ-DEL-SOLAR, *Guest Editor*
Universidad de Chile
Department of Electrical Engineering and Advanced Mining Technology Center
Santiago, 837-0451 Chile

REFERENCES

[1] A. A. Salah, J. Ruiz-del Solar, Ç. Meriçli, and P.-Y. Oudeyer, "Human Behavior Understanding," in *Proc. 3rd Int. Workshop Human Behavior Understanding HBU 2012*, Algarve, Portugal, Oct. 7, 2012, LNCS 7559, Springer-Verlag, Berlin Heidelberg.

[2] A. Mehrabian, *Nonverbal communication*. Piscataway, NJ, USA: Transaction Publishers, 1977.

[3] M. Knapp,, J. Hall, and T. Horgan, *Nonverbal communication in human interaction*. Independence, KY, USA: Cengage Learning, 2013.

[4] S. M. Nguyen and P.-Y. Oudeyer, "Active choice of teachers, learning strategies and goals for a socially guided intrinsic motivation learner," *Paladyn*, vol. 3, no. 3, pp. 136–146, 2013.

[5] A. A. Salah, T. Gevers, N. Sebe, and A. Vinciarelli, "Challenges of human behavior understanding," in *Human Behavior Understanding*. Berlin, Germany: Springer-Verlag, 2010, pp. 1–12.

[6] A. A. Salah, J. Ruiz-del Solar, Ç. Meriçli, and P.-Y. Oudeyer, "Human behavior understanding for robotics," in *Human Behavior Understanding*. Berlin, Germany: Springer-Verlag, 2012, pp. 1–16.

[7] B. E. Stein and M. A. Meredith,, *The Merging of the Senses*. Cambridge, MA, USA: MIT Press, 1993.

[8] L. B. Cohen, H. H. Chaput, and C. H. Cashon, "A constructivist model of infant cognition," *Cogn. Develop.*, vol. 17, no. 3, pp. 1323–1343, 2002.

Albert Ali Salah (M'06) received the Ph.D. degree from Boğaziçi University, Istanbul, Turkey.

From 2007 to 2011, he was with the CWI Institute, Amsterdam, The Netherlands, and with the Informatics Institute, University of Amsterdam, Amsterdam, from 2009 to 2011. He is currently an Assistant Professor with Boğaziçi University. His research interests include biologically inspired models of learning and vision, pattern recognition, biometrics, multimodal interaction, and human behavior understanding. He has more than 100 publications in related areas, including an edited book on computer analysis of human behavior.

Dr. Salah received the inaugural EBF European Biometrics Research Award in 2006, for his work on facial feature localization. He initiated the International Workshop on Human Behavior Understanding (HBU) in 2010 and served as its cochair since. He is a Member of the ACM and the IEEE AMD Technical Committee, IEEE Biometrics Council, the eNTERFACE Steering Committee, and the RoboCup Turkish National Committee. He is an Associate Editor of the *Journal of Ambient Intelligence and Smart Environments* and the IEEE TRANSACTIONS ON AUTONOMOUS MENTAL DEVELOPMENT.

Pierre-Yves Oudeyer received the M.Sc. degree is theoretical computer science from Ecole Normale Supérieure de Lyon, France, and the Ph.D. degree in artificial intelligence from the University Paris VI, Paris, France.

After eight years as a permanent researcher at Sony CSL Paris, he is now a Research Scientist at INRIA, France, where he heads the FLOWERS team. He has published a book, more than 60 papers in international journals and conferences, and received several prizes for his work in developmental robotics and on the origins of language. He is interested in the mechanisms that allow humans and robots to develop perceptual, motivational, behavioral, and social capabilities to become capable of sharing cultural representations.

Dr. Oudeyer is Editor of the IEEE CIS NEWSLETTER ON AUTONOMOUS MENTAL DEVELOPMENT, and an Associate Editor for the IEEE TRANSACTIONS ON AUTONOMOUS MENTAL DEVELOPMENT, *Frontiers in Neurorobotics*, and the *International Journal of Social Robotics*.

Çetin Meriçli (M'04) received the Ph.D. degree in computer science from Boğaziçi University, Istanbul, Turkey.

He is a Senior Robotics Engineer at the National Robotics Engineering Center (NREC) of the Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, USA. He was a Postdoctoral Fellow at the Computer Science Department, Carnegie Mellon University prior to joining NREC. His research interests include robot learning from human demonstration and feedback, interactive learning, sliding autonomy through learning, longterm autonomy and lifelong learning, developmental and cognitive robotics, human–robot interaction, robot vision, data driven high-fidelity robot simulation, probabilistic robotics, robot soccer, multirobot coordination and planning, and software engineering practices for robot software development. He was the general Cochair of RoboCup 2011, Chair of the AAAI 2012 Fall Symposium on Robots Learning Interactively from Human Teachers (RLIHT), Cochair of the 3rd Workshop on Realizing Artificial Intelligence Synergies in Software Engineering (RAISE'14), and Cochair of the Workshop on Humanoid Robots Learning from Human Interaction at IEEE/RAS Humanoids 2010.

Dr. Meriçli is a Founding Member of the RoboCup Turkey National Committee. He is a Member of AAAI, the IEEE Robotics and Automation Society, and IEEE Computational Intelligence Society. He is an Editor of the *Journal of Unmanned Systems Technology*.

Javier Ruiz-del-Solar (S'88–M'97–SM'04) received the Diploma degree in electrical engineering, the M.S. degree in electronic engineering from the Technical University Federico Santa Maria, Valparaiso, Chile, in 1991 and 1992, respectively, and the Doctor Engineer degree from the Technical University of Berlin, Berlin, Germany, in 1997.

In 1998, he joined the Department of Electrical Engineering, Universidad de Chile, Santiago, Chile, as an Assistant Professor. In 2005, he became an Associate Professor and in 2010, a Professor. Since 2009, he has been an Executive Director of the Advanced Mining Technology Center, Universidad de Chile. His research interests include mobile robotics, computer and robot vision, and the development of automation technologies for mining applications.

Dr. Ruiz-del-Solar received the 2004 RoboCup Engineering Challenge Award, the 2003 IEEE RAB Achievement Award, and the RoboCup@Home Innovation Award in 2007 and 2008.