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Intelligent Assistive Robotic Systems for the elderly: Two real-life use cases *

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ABSTRACT

Mobility impairments are prevalent in the elderly population and constitute one of the main causes related to difficulties in performing Activities of Daily Living (**ADL**s) and consequent reduction of quality of life. When designing a user-friendly assistive device for mobility constrained people, it is important to take into account the diverse spectrum of disabilities, which results into completely different needs to be covered by the device for each specific user. An intelligent adaptive behavior is necessary for the deployment of such systems. Also, elderly people have particular needs in specific case of performing bathing activities, since these tasks require body flexibility. We explore new aspects of assistive living via intelligent assistive robotic systems involving human robot interaction in a natural interface. Our aim is to build assistive robotic systems, in order to increase the independence and safety of these procedures. Towards this end, the expertise of professional carers for walking or bathing sequences and appropriate motions have to be adopted, in order to achieve natural, physical human - robot interaction. Our goal is to report current research work related to the development of two real-life use cases of intelligent robotic systems for elderly aiming to provide user-adaptive and context-aware assistance.

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CCS Concepts

•Human-centered computing → HCI design and evaluation methods; •Computer systems organization → Robotics;

Keywords

Intelligent Assistive Robotic Systems; Assistive HRI; Mobility Assistance; Bathing Assistance

1. INTRODUCTION

Elder care constitutes a major issue for modern societies, as the elderly population constantly increases. One important measure of morbidity and quality of life is a person's ability to perform ADLs such as washing the body, dressing, transferring, toileting and feeding [6],[11]. A number of studies have assessed the extent to which loss of function across ADLs progresses hierarchically and it has been shown that just as there is an orderly pattern of development of function in the child, there is an ordered regression as part of the natural process of aging [6] and quite often the order of the later is the reverse of the order of the former. Loss of function typically begins with those ADLs, which are most complex and least basic, while these functions that are most basic and least complex can be retained to the last.

Mobility problems are very common in seniors. As people age they have to cope with instability and lower walking speed [8]. It is well known that mobility impairments constitute a key factor impeding many activities of daily living important to independent living, having a strong impact in productive life, independence, physical exercise, and self-esteem [7]. Most people with mobility issues, patients or elders, have to use walkers in their everyday activities and they need the constant supervision of a carer. The social and economic significance of solving these issue should not be underestimated. Robotics seems to fit naturally to the role of providing user-adaptive mobility and ambulation assistance to the elderly, since it can incorporate features such as posture support and stability enhancement, walking assistance, navigation and cognitive assistance in indoor and outdoor environments, health monitoring etc.

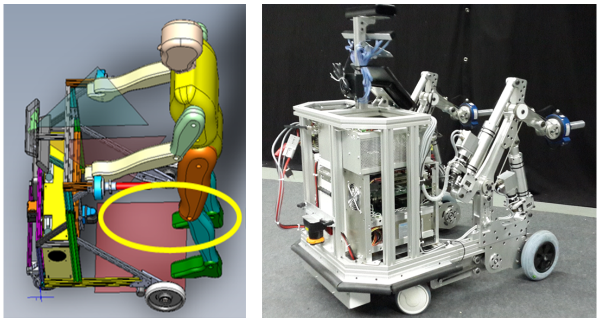

Figure 1: Use Case 1: Mobility Assistance. Left: A CAD representation of a robotic mobility assistive device. Right: The MOBOT robotic platform.

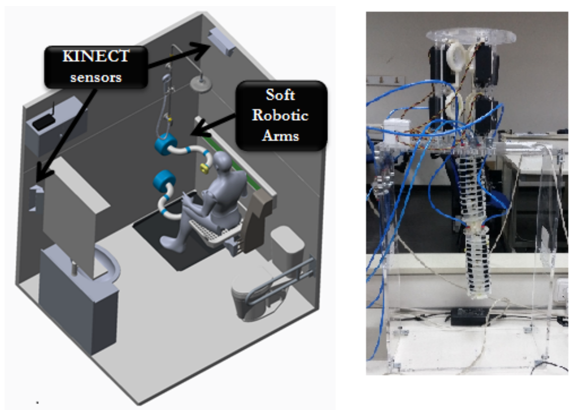

Figure 2: User case 2: Bathing Assistance. Left: A CAD design of the robotic bath assistive system. Right: The I-SUPPORT first soft-arm prototype robot.

Washing the body (either showering or bathing) is one of the most complex and least basic activities and, thus, is among the first ADLs that typically suffer significant loss of function. Furthermore, older adults showering is reported as one of the first ADLs that residents of a nursing home population lost the ability to perform, [6]. This clearly suggests that support in shower and bathing activities, as an early marker of ADL disability, will foster independent living for persons prone to loss of autonomy and relieve the caring and nursing burden of the family, domiciliary services, medical centers and other assisted living environments. Roboticists have already proposed solutions to this basic personal care disability, with either static physical interaction [10, 19, 18], or mobile solutions [1, 9, 5]. Most of these focus exclusively on a body part e.g. the head, and support people on performing other personal care activities with rigid manipulators.

This paper reports current research work related to the control of two real-life use cases of intelligent robotic systems for elderly aiming to provide user-adaptive and context-aware assistance. To achieve such targets, a large spectrum of multimodal sensory processing and interactive control modules need to be developed and seamlessly integrated,

Figure 3: Internal gait phases of human normal gait cycle used in the MOBOT project to extract gait parameters and analyse walking impairments.

that can, track and analyse human motions and actions, in order to detect unlike situations and estimate user needs, while predicting at the same time the user (short-term or long-range) behaviors in order to adapt robot control actions and supportive behaviours accordingly. User-oriented human-robot interaction and control refers to the functionalities that couple the motions, the actions and, in more general terms, the behaviours of the assistive robotic device to the user.

This paper is structured around two main components of the robot control architecture, namely: (i) the first real-life use case of a robotic walking rollator system for gait tracking monitoring and analysis, and (ii) the second real-life use case of a robotic bath system for body motion behavior adaptation.

2. REAL-LIFE USE CASE 1: MOBILITY ASSISTANCE

The first real-life use case consists of the research work conducted in the frames of an EU funded research project **MOBOT**[1], aiming to develop an intelligent robotic rollator and to provide user-adaptive and context-aware walking assistance, Fig. 1. The developed experimental prototype consists of a robotic rollator equipped with sensors such as: laser range sensors scanning the walking area for environment mapping and obstacle detection, detecting also lower limbs movement at the back; force/torque handle sensors; two Kinect sensors to record users' upper body movements and the lower limbs and an array of 8-microphone MEMS for audio capturing.

The main motivation behind this work derives from our vision of developing and advancing robotic technologies enabling the development and deployment of cognitive assistive devices that can monitor and understand specific forms of human walking activities in their workspace, in order to deduce the particular needs of a user regarding mobility and ambulation. The ultimate goal is to provide context-aware support [2], and intuitive, user-adapted assistance to users experiencing mild to moderate mobility and/or cognitive impairments in domestic environments.

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[1] http://www.mobot-project.eu/

2.1 HRI: Gait Monitoring & Analysis

Research work is conducted for developing a reliable pathological walking assessment system, that can operate on-line and in real-time enabling the robotic assistive device to continuously monitor and analyse the gait characteristics of the user in order to recognise walking patterns that can be classified as pathological requiring specific attention and handling by the system. Our system uses an onboard laser rangefinder sensor mounted on a robotic assistive device to detect and track the human legs by using appropriate algorithms (a non-intrusive solution that does not interfere with human motion). With respect to gait analysis and assessment, as opposed to most of the literature available on the topic, our approach is completely non-intrusive based on the use of a typical non-wearable device. Instead of using complex models and motion tracking approaches that require expensive or bulky sensors and recording devices that interfere with human motion, the measured data used in this work is provided by a standard laser rangefinder sensor mounted on the prototype robotic rollator platform. A Hidden Markov Model (**HMM**) approach is used to perform statistical modeling of human gait. An HMM has well suited statistical properties, and it is able to capture the temporal state-transition nature of gait. In our work, we have proposed and analyzed extensively the properties of an HMM system and its applications for modelling normal human gait [15], as well as for pathological gait recognition [16]. Finally, we have validated the extraction of gait parameters from the range data based on HMM in [14].

Based on this modeling seven-state representation is used in order to follow the typical definition of stance and swing phase events for normal human gait, which are depicted in Fig. 3. The recognized sequence of gait phases is indicative of the subject's underlying pathology, since it differs from the normal gait phase sequences. Using this segmentation we can compute the gait parameters from the range data. Each recognized gait cycle is used for the gait parameter extraction. The *stride time* equals the duration of the recognized gait cycle. Given the time segmentation by the HMM, we have isolated the stance and swing phase of the gait cycle, and computed the *swing time* between the gait phases **IW** and **MW** and the stance time between the gait phases **IC** and **PW**. The *right and left step lengths* are computed by the absolute maximum distance traveled by each leg, while their summation during the gait cycle provides the *stride length*.

The estimated gait parameters are indicative of particular pathologies, [13]. This indication will trigger control assistive actions and behaviors (velocity adjustment, approach of the patient due to changes in gait patterns) from the robotic assistant that follows the user. It is therefore crucial to have a robust tracking system, as the estimated gait parameters of the user are essential for the low level robot controller, [3].

2.2 Experimental Results for Use Case 1

The experimental results regarding the walking assistive device presented in this section are based on data collected during a full-scale experimental study conducted at the premises of Agaplesion Bethanien Hospital - Geriatric Center (University of Heidelberg) at the frames of the EU-funded FP7 research project MOBOT. Patients with moderate to mild impairment, according to pre-specified clinical inclusion criteria, took part in this experiment. We have used a Hokuyo Rapid URG laser sensor (UBG-04LX-F01), mounted on the robotic platform of Fig. 1 (scanning was performed at a horizontal plane below knee level).

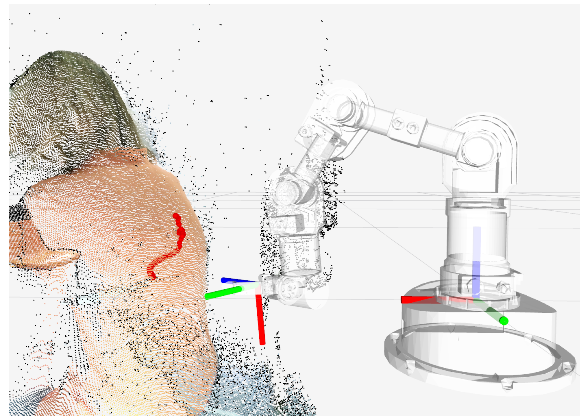


Figure 4: An experiment of user-adaptive trajectory tracking in the I-SUPPORT project: a robotic arm tracking a sinusoidal trajectory adapted on the back region of a female subject (curved surface captured by means of point cloud data).

An initial performance assessment of the HMM-based methodology regarding the extraction of gait parameters is presented. An example of the exact gait phase recognition sequence provided by the HMM-based approach for the full duration of the strides performed by one subject is depicted in Fig. 5, where the blue and red lines are presenting the displacement of the left and right leg in the sagittal plane, respectively, during about the three strides (axis on the right), while the grey line depicts the gait phase segmentation that was extracted from the HMM (axis on the left). In the same figure, the segmentation of each stride along with the computed gait parameters for the first stride are presented.

3. REAL-LIFE USE CASE 2: BATHING ASSISTANCE

The second real-life use case consists of the research work related to the **I-SUPPORT**[2] service robotics system, which will be developed in the context of a EU Horizon2020 Project, Fig. 2. The goal is to develop a robotic shower system in order to enable independent living for elderly so as to improve their life quality. This service robotics system is based on the development and integration of an innovative, modular, ICT-Supported service robotics system that supports and enhances frail older adults' motion and force abilities and assists them in successfully, safely and independently completing the entire sequence of showering tasks (i.e. pouring water, soaping, body part scrubbing, etc.), such as properly washing their back, their upper parts, their lower limbs, their buttocks and groin, and to effectively use the towel for drying purposes.

The core system functionalities identified as important from a clinical perspective (taking into account impairments, limitations and user requirements) are the tasks for bathing

[2]http://www.i-support-project.eu/

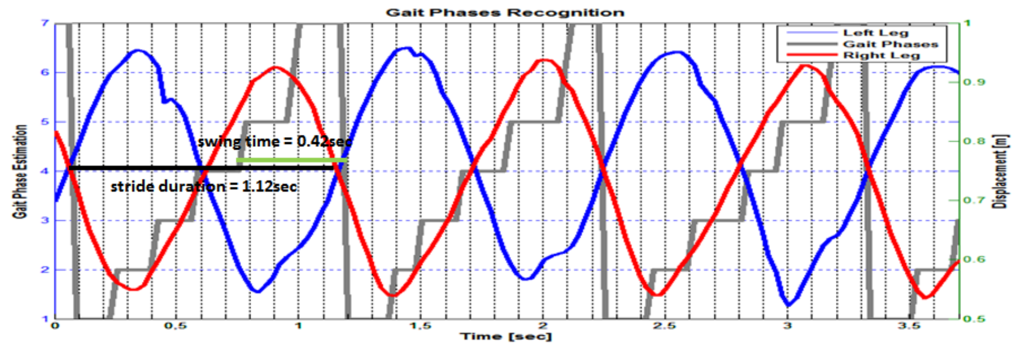


Figure 5: Subject's gait phase recognition and gait parameters during the first stride as estimated by the HMM-based approach, according to grey line (axis on the left). The blue and red lines are the displacement of the left and right leg in the sagittal plane, respectively (axis on the right).

the distal region and the back region [21]. The experimental prototype in this case includes three Kinect sensors, that reconstruct the 3D pose of the human and the robot, recognizing also user gestures and an audio system including 8 distributed condenser microphones. The degree of automation will vary according to the user's preferences and disability level [4]. The robotic system provides elderly showering abilities enhancement, whereas the Kinect sensors are used for user perception and HRI applications.

The robotic arms will be constructed with soft materials (rubber, silicon etc.) and will be actuated with the aid of tendons and pneumatic chambers, providing the required motion to the three sections of the robotic arm. This configuration makes the arms safer and more friendly for the user, since they will generate little resistance to compressive forces, [17, 12]. Moreover, the combination of these actuation techniques increases the dexterity of the soft arms and allows for adjustable stiffness in each section of the robot. The end-effector section, which will interact physically with the user, will exhibit low stiffness achieving smoother contact, while the base sections supporting the robotic structure will exhibit higher stiffness values.

3.1 HRI: Body Motion Behavior Adaptation

Research work is conducted for developing a reliable real-time end-effector motion planning method for an assistive bath robotic system, using on-line Point-Cloud information. Visual information of the user will be obtained from Kinect depth cameras. These cameras will be mounted on the wall of the shower room in a proper configuration in order to provide full body view of the user, Fig. 2. It is important to mention that information exclusively from depth measurements will be used to protect the user's personal information. Accurate interpretation of the visual information is a prerequisite for human perception algorithms (e.g. accurate body part recognition and segmentation [20]). Furthermore, depth information will be used as a feedback for robot control algorithms closing the loop and defining the operational space of the robotic devices.

Our method is independent of the robot model, therefore it can be applied to any robotic manipulator. This system will help elderly during bathing, by enhancing mobility, manipulation and force exertion abilities, and increasing in that way the independence and safety of the showering activity. This is a demanding task, since suitable washing actions should be adapted on different user body-part's deformable surface and motion. Adaptability to different users is also a very important feature of the system. Different users have dissimilar body areas and needs during the washing sequence.

Thus, we consider the motion behavior problem of a robotic manipulator's end-effector, which operates over a curved deformable surface (e.g. user's body part). The core of this motion behavior task is to calculate on the fly the reference pose for the end-effector of the robotic arm, which will let the robotic manipulator execute predefined surface tasks (e.g. scrubbing the user's back) and at the same time to be compliant with this body part. This is a challenging task, since all human's body parts are non-planar surfaces, that are moving and deforming either systematically (e.g. user's breathing motion) or randomly. Moreover, the user will have constant communication with the system (e.g. audio - gestural commands) and will be able to change the state and the parameters of the system with hand gestures, which may interfere to the robot's operation.

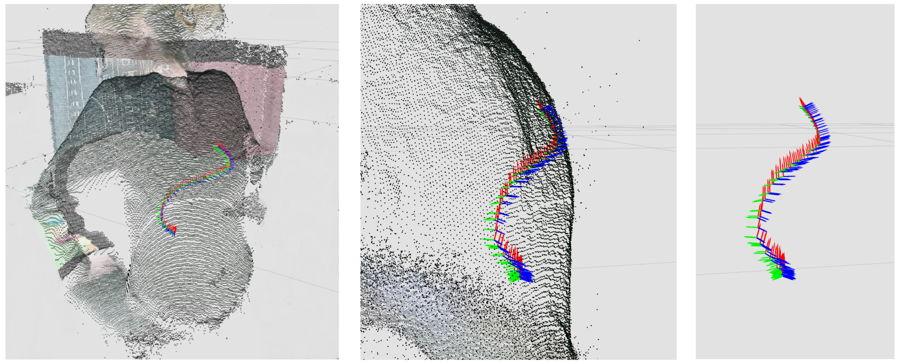
3.2 Experimental Results for Use Case 2

The experimental results regarding the robotic bath assistive device presented in this section are based on data collected during an experimental study with healthy subjects. The experimental setup includes a Kinect-v2 Camera providing depth data for the back region of a subject. The segmentation of the subjects' back region is implemented, for the purposes of this experiment, by simply applying a Cartesian filter to the Point-Cloud data. The setup also includes a 5 DOF Katana arm by Neuronics, Fig. 4.

The experiments conducted include the following of a simple sinusoidal path, keeping simultaneously a constant distance and perpendicular relative orientation to the surface of a female subject's back region, Fig. 6. These experiments were conducted, in order to highlight the adaptability of the algorithm to real users.

4. CONCLUSIONS

This paper presents current research work that aims at the development of intelligent robotic systems for the elderly, to provide user-adaptive and context-aware assistance. To achieve such targets, a large spectrum of multimodal sen-



(a) (b) (c)

Figure 6: Experiment on a female subject. (a) Adaptation of the sinusoidal path on the curved surface of a female subject represented with PointCloud data. (b) A zoomed aspect of the experiment depicting in more detail the adaptation of the path. (c) A more clear view of the zoomed path without the PointCloud.

sory processing and interactive control modules need to be developed and seamlessly integrated. This paper focuses on user-oriented human-robot interaction and control, by which we refer to the functionalities that couple the motions, the actions and, in more general terms, the behaviours of the assistive robotic devices to the user. In this paper we present methods and current results targeting two real-life use-cases of assistive robotic systems in the frames of two EU-funded research projects, related to: 1) the development of a reliable gait tracking and classification system, for which we have developed an approach based on HMMs, which can operate online by processing raw sensorial data provided by an onboard laser rangefinder sensor, 2) the development of a real-time user-adaptive robot motion planning and trajectory tracking approach for defining the behavior of a bath robot device by processing depth data provided by a sensor, whose task is to interact in a friendly way with moving and variably curved body parts.

This paper summarizes the framework and presents experimental results obtained using real data both from patients and normal subjects. These results are very promising depicting the capacities of the presented methodologies, both in terms of action recognition and gait characterisation as well as regarding robot motion control based on non-contact sensorial data. Nevertheless, the results demonstrate that there is significant space for increasing the accuracy of the systems. Further comparative analysis and full-scale validation of the methodological frameworks constitutes one of the main objectives of current research work.

5. REFERENCES

[1] C. Balaguer, A. Gimenez, A. Huete, A. Sabatini, M. Topping, and G. Bolmsjo. The mats robot: service climbing robot for personal assistance. *Robotics Automation Magazine, IEEE*, 13(1):51–58, March 2006.

[2] P. Brezillon. Context in problem solving: A survey. *The Knowledge Engineering Review*, 14:1–34, 1999.

[3] T. C. Chalvatzaki G., Papageorgiou X.S. Gait modelling for a context-aware user-adaptive robotic assistant platform. In *Proceedings of the 8th International Conference on Integrated Modeling and Analysis in Applied Control and Automation, Bergeggi, Italy, September 21 - 23, 2015 (Best Paper Award).*

[4] A. C. Dometios, X. S. Papageorgiou, C. S. Tzafestas, and P. Vartholomeos. Towards ict-supported bath robots: Control architecture description and localized perception of user for robot motion planning. In *2016 24th Mediterranean Conference on Control and Automation (MED)*, pages 713–718, June 2016.

[5] B. Driessen, H. Evers, and J. v Woerden. ManusŮa wheelchair-mounted rehabilitation robot. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 215(3):285–290, 2001.

[6] D. D. Dunlop, S. L. Hughes, and L. M. Manheim. Disability in activities of daily living: patterns of change and a hierarchy of disability. *American Journal of Public Health*, 87:378–383, 1997.

[7] P. D. Foundation. Statistics for parkinson's disease, 2010.

[8] T. Herman et. al. Gait instability and fractal dynamics of older adults with a ŞcautiousŤ gait: why do certain older adults walk fearfully? *Gait Posture 2005*.

[9] M. Hillman, K. Hagan, S. Hagan, J. Jepson, and R. Orpwood. The weston wheelchair mounted assistive robot - the design story. *Robotica*, 20:125–132, 3 2002.

[10] T. Hirose, S. Fujioka, O. Mizuno, and T. Nakamura. Development of hair-washing robot equipped with scrubbing fingers. In *Robotics and Automation (ICRA), 2012 IEEE International Conference on*, pages 1970–1975, May 2012.

[11] S. Katz, A. Ford, R. Moskowitz, B. Jackson, and M. Jaffe. Studies of illness in the aged: The index of adl: a standardized measure of biological and psychosocial function. *JAMA*, 185(12):914–919, 1963.

[12] M. Manti, A. Pratesi, E. Falotico, M. Cianchetti, and C. Laschi. Soft assistive robot for personal care of elderly people. In *2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, pages 833–838, June 2016.

[13] A. Muro-de-la-Herran et. al. Gait analysis methods: An overview of wearable and non-wearable systems,

highlighting clinical applications. *Sensors 2014*, 14(2):3362, 2014.

[14] X. S. Papageorgiou, G. Chalvatzaki, K. N. Lianos, C. Werner, K. Hauer, C. S. Tzafestas, and P. Maragos. Experimental validation of human pathological gait analysis for an assisted living intelligent robotic walker. In *2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, pages 1086–1091, June 2016.

[15] X. S. Papageorgiou, G. Chalvatzaki, C. S. Tzafestas, and P. Maragos. Hidden markov modeling of human normal gait using laser range finder for a mobility assistance robot. In *2014 IEEE International Conference on Robotics and Automation (ICRA)*, pages 482–487, 2014.

[16] X. S. Papageorgiou, G. Chalvatzaki, C. S. Tzafestas, and P. Maragos. Hidden markov modeling of human pathological gait using laser range finder for an assisted living intelligent robotic walker. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 6342–6347, 2015.

[17] T. G. Thuruthel, E. Falotico, M. Cianchetti, F. Renda, and C. Laschi. Learning global inverse statics solution for a redundant soft robot. In *Proceedings of the 13th International Conference on Informatics in Control, Automation and Robotics*, pages 303–310, 2016.

[18] M. Topping. An overview of the development of handy 1, a rehabilitation robot to assist the severely disabled. *Artificial Life and Robotics*, 4(4):188–192.

[19] Y. Tsumaki, T. Kon, A. Suginuma, K. Imada, A. Sekiguchi, D. Nenchev, H. Nakano, and K. Hanada. Development of a skincare robot. In *Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on*, pages 2963–2968, May 2008.

[20] A. Vedaldi, S. Mahendran, S. Tsogkas, S. Maji, R. Girshick, J. Kannala, E. Rahtu, I. Kokkinos, M. Blaschko, D. Weiss, et al. Understanding objects in detail with fine-grained attributes. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 3622–3629, 2014.

[21] J. Werle and K. Hauer. Design of a bath robot system: User definition and user requirements based on international classification of functioning, disability and health (icf). In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pages 459–466, Aug 2016.