Proceedings

CYBATHLON Symposium on Assistive and Wearable Robotics (AsWeR 2019)

16 – 17 May, 2019, Karlsruhe

Organizer

Prof. Dr.-Ing. Tamim Asfour
Karlsruhe Institute of Technology
KIT Center Information · Systems · Technologies (KCIST)

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Invited Speakers

Roland Auberger

Otto Bock Healthcare

Roland Auberger was born in Linz, Austria in 1977. He received his master’s degree (Dipl.-Ing.) in Mechatronics from the Johannes Kepler University Linz, Austria in 2002. From 2002 to 2004, he was a Research Assistant at the Institute for Robotics at the Johannes Kepler University Linz, Austria. Since 2004 he is with the research and development department of Otto Bock Healthcare Products GmbH, Vienna, Austria. Since 2015 he is also member of the Sensory-Motor Systems (SMS) Lab, Institute of Robotics and Intelligent Systems (IRIS), Department of Health Sciences and Technology (D-HEST), ETH Zurich, Switzerland. He is author of nine granted patents and several patent applications. His research interests include intelligent orthotics and prosthetics, lower limb exoskeletons, and rehabilitation robotics.

Gordon Cheng

Technical University of Munich

Gordon Cheng holds the Chair of Cognitive Systems at Technical University of Munich (TUM). He is Founder and Director of the Institute for Cognitive Systems in the Department of Electrical and Computer Engineering at TUM. He is also the coordinator of the CoC for Neuro-Engineering – Center of Competence Neuro-Engineering within the department and program director of the ENB Elite Master of Science program in Neuroengineering. He is also involved in several major European Union Projects. Over the past years Gordon Cheng has been the co-inventor of approximately 20 patents and is the author of approximately 300 technical publications, proceedings, editorials and book chapters.

Martin Giese

University of Tübingen

M. Giese has studied Electrical Engineering and Psychology at the Ruhr University in Bochum. After a Postdoc at the Dept. of Brain and Cognitive Science at M.I.T., he founded in 2000 the Boston Research Laboratory of Honda Americas. He received his habilitation at the Department of Informatics at the University of Ulm. From 2007 to 2008 he was Senior Lecturer at the Department of Psychology at the University of Wales, Bangor. Since 2008 he is head of the Section for Computational Sensomotorics at the Centre for Integrative Neuroscience and the Hertie Institute at the University Clinic Tübingen. The main topic of his lab are the perception and control of complex body motion, related neural models, and technical and clinical applications of learning-based representations for the synthesis and analysis of complex body movements.

Herman van der Kooij

University of Twente

Herman van der Kooij, chairs the BioMechatronics group. He received his Phd with honors (cum laude) in 2000 and is professor in Biomechatronics and Rehabilitation Technology at the Department of Biomechanical Engineering at the University of Twente, and Delft University of Technology. His expertise and interests are in the field of human balance and motor control, adaptation, and learning. His group designed various rehabilitation, wearable robots, diagnostic, and assistive robotics. He received several awards for excellent researchers in 2001 and 2015 respectively. Currently he leads the Dutch national program Wearable Robotics and the Dutch national 4TU Soft Robotics program.

Angelika Peer

Free University of Bozen-Bolzano

Angelika Peer is Full Professor at the Free University of Bozen-Bolzano (Italy) since November 2017. From 2014 to 2017 she was Full Professor at the Bristol Robotics Laboratory, University of the West of England, Bristol, UK. Before she was senior researcher and lecturer at the Institute of Automatic Control Engineering and TUM-IAS Junior Fellow of the Institute of Advanced Studies of the Technical University of Munich, Germany. She received the Diploma Engineering degree in Electrical Engineering and Information Technology in 2004 and the Doctor of Engineering degree in 2008 from the Technical University of Munich. Her research interests include robotics, control and human system interaction.

Domenico Prattichizzo

University of Siena

Professor of Robotics at the University of Siena, Senior Scientist at the Istituto Italiano di Tecnologia in Genova, Fellow of the IEEE society, President of Eurohaptics Society, and Co-founder of the startup WEART, a startup for VR and AR applications. Human and robotic hands together with the art of manipulating real and virtual objects have always polarized his research that has recently focused on wearable haptics and wearable robotics. He has been selected among the best two Cross-Cutting Challenges Initiatives at the IEEE Haptic Symposium 2018 in San Francisco with the theme “The path to intelligent clothes and objects able to change the way we communicate with the world”. Author of more than 250 scientific articles in the field of robotics and virtual reality.

Robert Riener

ETH Zürich

Robert Riener is full professor for Sensory-Motor Systems at the Department of Health Sciences and Technology, ETH Zurich, and full professor of medicine at the University Hospital Balgrist, University of Zurich. His work focuses on the investigation of the sensory-motor interactions between humans and machines and the development of user-cooperative rehabilitation robots, exoskeletons and virtual reality technologies. Riener is the initiator and organizer of the Cybathlon. In 2018 Riener obtained the honorary doctoral degree from the University of Basel.

Arndt Schilling

University Medical Center Göttingen

Arndt Schilling is a medical doctor and a molecular biologist by training and a scientist and inventor out of passion. He held professorships in Biomaterial Research and Experimental Plastic Surgery at the Technical Universities of Hamburg-Harburg and Munich and is now leading research and development at the Clinic of Trauma Surgery, Orthopedics and Plastic Surgery at UMG. Here he founded the Applied Rehabilitation Technology Lab to explore with his team how to make novel technologies available to enable doctors to improve the life of their patients.

Andre Seyfarth

Technical University of Darmstadt

Since July 2011 Andre Seyfarth has been head of the Department of Sports Biomechanics at the Institute of Sports Science at the TU Darmstadt. Previously, from 2003 to 2011, he established the Lauflabor working group (lauflabor.de) in Jena, which has also completely moved to Darmstadt since 2012. His research focuses on experimental motion studies on humans and animals, biomechanical and neuromuscular motion models as well as technical research systems (e.g. walking robots, prostheses, demonstrators).

Patrick van der Smagt

Volkswagen Group Machine Learning Research Lab

Patrick van der Smagt is director of the open-source Volkswagen Group Machine Learning Research Lab in Munich, focusing on probabilistic deep learning for time series modelling, optimal control, reinforcement learning, robotics, and quantum machine learning. He previously directed a lab as professor for machine learning and biomimetic robotics at the Technical University of Munich while leading the machine learning group at the research institute fortiss, and before founded and headed the Assistive Robotics and Bionics Lab at the DLR Oberpfaffenhofen. He is founding chairman of a non-for-profit organization for Assistive Robotics for tetraplegics and co-founder of various tech companies.

Gerwin Smit

Technical University of Delft

Gerwin Smit is an assistive professor at the department of biomechanical engineering (BME) at TU Delft. His research focuses on how to design innovative prosthetic devices using the newest technologies. These devices should be comfortable to be worn, and they should be intuitively controllable by the prosthesis user, with little effort. Besides the research on prosthetic hands, he also works on the development of a new prosthetic knee, and on other medical and rehabilitation assisting devices.

Symposium on Assistive and Wearable Robotics (AsWeR 2019)

16 - 17 May, 2019, Karlsruhe

Venue

Messe Karlsruhe

Messeallee 1
D-76287 Rheinstetten
https://www.rehab-karlsruhe.com/en/register-plan/for-visitors/getting-there/

Registration

Registration opens 16 May, 10:00 am

Duration of the presentations

Keynotes	30 minutes (25 minutes talk + 5 minutes Q&A)
Oral presentations	10 minutes (8 minutes talk + 2 minutes Q&A)
Interactive presentations	30 minutes poster session

Programme

Thursday, May 16

Time	Session
12:45	**Lunch**
13:45	**Opening** **Tamim Asfour**, KIT, Germany
14:00	**Cybathlon: Moving People and Technology** ***Robert Riener,*** *ETH Zürich, Switzerland*
14:30	**Human Balance Control: From Experiments to Predictive Models to Applications in Wearable Robots** ***Herman van der Kooij,*** *University of Twente, Netherlands*
15:00	**Machine learning in BCI: getting as smart as the brain** ***Patrick van der Smagt,*** *Volkswagen Group Machine Learning Research Lab, Germany*
15:30	**Coffee Break**
16:00	**Processes in Restoring Sense of Touch to Spinal Cord Injured Patients** ***Gordon Cheng,*** *Technical University of Munich, Germany*
16:30	**Human-centred robotic systems: From intelligent mobility assistant robots to robot avatars (cancelled)** ***Angelika Peer,*** *Free University of Bozen-Bolzano, Italy*
16:30	**Biologically-inspired modeling of complex human body movements and applications in robotics** ***Martin Giese,*** *University of Tübingen, Germany*
17:00	**CYBATHLON Interactive Session**
17:30	SoftHand Pro: a Robust and Adaptive Bionic Hand to Enable Physical Interaction *Cristina Piazza, Giorgio Grioli, Antonio Bicchi and Manuel Giuseppe Catalano*
17:40	Simultaneous and Proportional Myoelectric Control of Hand Prostheses - Evaluation in Daily Life *Janne Hahne, Meike Schweisfurth, Mario Koppe, Dario Farina and Arndt Schilling*

17:50	The KIT Prosthetic Hand *Pascal Weiner, Julia Starke, Samuel Rader, Felix Hundhausen and Tamim Asfour*
18:00	Task decomposition as a new approach for assessing the prosthesis performance in standardized tests *Jeremy Mouchoux, Arndt Schilling and Marko Markovic*
18:10	Textile-Based Soft Wearable Actuators *John Nassour and Fred Hamker*
18:20	Human Factors as Guiding Principles for Wearable Robot Design *Philipp Beckerle*
18:30	**Transfer to restaurant**
19:00	**Symposium Dinner at** **Kesselhaus Färberei** **Griesbachstraße 10 c** **76185 Karlsruhe**

Friday, May 17

Time	Session
9:00	**Robotic Technology in Everyday Use Assistive Devices: A Reality Check** ***Roland Auberger,*** *OttoBock Healthcare, Austria*
9:30	**Bionic Prostheses for Trauma Surgery Patients** ***Arndt Schilling,*** *University Medical Center Göttingen, Germany*
10:00	Magnetometer-free Inertial Motion Capture System with Visual Odometry *Atabak Nezhadfard, Bertram Taetz, Patrick Vonwirth, Karsten Berns and Gabriele Bleser*
10:10	Online planning and control of ball throwing by the humanoid robot COMAN and validation exploiting VR in rehabilitation scenarios with ataxia patients *Jindrich Kodl, Albert Mukovskiy, Pouya Mohammadi, Milad Malekzadeh, Nick Taubert, Doris Broetz, Tjeerd M.H. Dijkstra, Jochen J. Steil and Martin A. Giese*
10:20	**Coffee Break**
10:50	**Augmenting Humans with Supernumerary Robotic Fingers** ***Domenico Prattichizzo,*** *University of Siena, Italy*
11:20	**Intuitive Grasping, Perspectives on Prosthetic Development** ***Gerwin Smit,*** *TU Delft, Netherlands*
11:50	**Biomechanical gait models and concepts - how can they help to analyze and synthesize motions?** ***André Seyfarth,*** *Technische Universität Darmstadt*
12:20	A lower limb segment based control concept for exoskeletons with anti-gravity support *Martin Grimmer, Kai Schmidt, Jaime Duarte, Lukas Neuner, Gleb Koginov and Robert Riener*
12:30	A Lower Limb Exoskeleton with Kinematically Compatible Joint Mechanisms *Jonas Beil, Charlotte Marquardt and Tamim Asfour*
12:40	Template-based control of prosthetic feet *Amirreza Naseri, Martin Grimmer, André Seyfarth and Maziar Ahmad Sharbafi*
12:50	**Closing**
13:00	**Lunch (Vouchers)**

13:00	**CYBATHLON Qualification Races**
14:00	**Transfer to the lab tour via tram (for those interested)** **Institute of Anthropomatics and Robotics, High Performance Humanoid Technologies (H2T)**

CYBATHLON Powered ARM and LEG Prosthesis Series

The CYBATHLON Prosthesis Series in Karlsruhe is a combined Series which includes two disciplines (arm and leg prosthesis). It will take place on May 17-18, 2019.

Further Information

Webpage CYBATHLON Prosthesis Series and Symposium:
http://www.cybathlon-symposium-karlsruhe-2019.org/

H2T Lab: http://www.humanoids.kit.edu

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Table of Contents

Human Factors as Guiding Principles for Wearable Robot Design

Philipp Beckerle[1]

Abstract— **Wearable robots are artifacts made to be used by human users in tight interaction. While supporting the user certainly requires specific functionalities from such devices, human factors are usually harder to grasp for the developer, but obviously of utmost importance. Recent research on upper limb as well as lower limb devices tries to improve the understanding of how such factors influence the experience of wearable robots and how this can be adressed in techical design. This paper discusses approaches to tackle this challenge and shows how human factors research can guide wearable robot design. Therefore, methodical accounts to invesitgate human factors from three perspectives, i.e., subjective experience, expert opinions, and human-in-the-loop experiments, are discussed.**

I. MOTIVATION AND PROBLEM DEFINITION

Wearable robot devices such as prostheses or exoskeletons for the upper and lower limbs recently receive a tremendous research interest [1], [2], [3]. Besides their potential of helping to address emerging issues of our ageing and less active societies, such devices are very interesting for human-robot interaction research [4]. Operating very closely to their users, wearable robots also interact very tightly, directly influence users' satisfaction and experiences, and might even be perceived as a part of their user's body [4]. Yet, all these human-related determinants are rather hard to comprehend and perhaps even harder to consider in technical design [5].

II. RELATED WORK

Subjective experience of aids such as prosthetic devices can be assessed through questionnaires, which either investigate how users experience their devices, their environment, and themselves globally [8], [10] or focus on specific aspects, e.g., their image of their own body [9]. While human factors appear to strongly influence device acceptance, most questionnaires have so far been used mostly for the evaluation of existing devices and not to guide design [5].

Expert opinions might be a possiblity to bridge this gap since they can reveal interrelations between the users' perspectives and the design and use of the devices [11], [5]. Moreover, expert knowledge supports revealing human factors and their technical potential in the first place, e.g., a recent study outlined lacks in user involvement during development of walking exoskeletons [12].

Human-in-the-loop approaches can help to tackle this lacking involvement by allowing users to explore early hardware realizations in safe environments and structured experiments [13], [14]. However, recent research rather seems to focus on functional and performance outcomes [15], [16], which are important, but do not address users' views directly.

III. OWN APPROACH AND CONTRIBUTIONS

Irrespective of the investigated technology, i.e., prosthetics, exoskeletons. etc., or the location on the body, i.e., upper/lower extremeties or others, human factors seem to play a key role in wearable robot design [8], [5]. Drawing on our previous research, a multidisciplinary approach seems to be required to consider human factors appripriately [5], [4]. To guide the design of wearable robots considering human factors, we proposed a methodical framework that ranks the relevance of technical design criteria based on their relations to human factors [5]. Therefore, subjective experience is surveyed to reveal human factors and the relation of these factors to technical requirements is assessed through and expert discussion. While we applied the method to lower limb prosthetics, a transfer to exoskeletons and the upper limbs is possible. Such additional studies are even required to evaluate and validate the suggested tools: a first validation indicates that our questionnaire, which explores the potential of human factors in lower limb prosthetic design, has good internal consistency.

Human-in-the-loop experiments help to take a closer look on how specific technical solutions interplay with certain human factors. One contribution of our research is to reveal how changes of the human-robot interface modulate the perceived embodiment of fake body parts: we revealed temporal requirements to motion control and tactile feedback [17] and substantiated that tactile feedback supports embodiment [**?**]. Moreover, embodiment is a promising quality measure of shared control and other augmentation approaches [18].

IV. CONCLUSION

Human factors appear to be very promising guiding principles for wearable robot design. Yet, standardized methods to involve users during design and fuse their input into the design process are scarce [5], [12]. Besides evaluating and validating previously proposed methods, future research should also consider participatory approaches, which enable users to take part more actively and continuously.

ACKNOWLEDGMENT

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A Lower Limb Exoskeleton with Kinematically Compatible Joint Mechanisms

Jonas Beil, Charlotte Marquardt and Tamim Asfour

***Abstract*— A good kinematic compatibility to the human body is a key requirement for lower limb exoskeletons that augment the capabilities of healthy users. We present the design of a new lower limb exoskeleton consisting of a previously developed self aligning hip joint mechanism which is combined with two Rolling Contact Joint at the knee and ankle. The joint mechanisms are actuated by four actuators per leg and 15 eccentric clamps allow a scaling of the device to body heights ranging from 1.54 m to 1.86 m. Simulation results indicate a comparable or improved kinematic compatibility to existing devices from literature. To the best of our knowledge this lower limb exoskeleton is the first device which consists of three kinematically compatible joint mechanisms.**

I. MOTIVATION AND PROBLEM DEFINITION

Augmenting exoskeletons assist healthy users performing physically demanding work, thereby preventing impairments of their musculo-skeletal systems. The ideal device is transparent until it induces assistive torques on the user's joints and does not hinder him when performing the task. Ideally, the corresponding human-exoskeleton joint axes are aligned automatically while the installation space remains small and the application of an actuator is simple. The goal of the presented work is to integrate previously developed joint mechanisms into a lower limb exoskeleton which scales to different body sizes and induces assistive torques on the main joint axis used during locomotion tasks.

II. RELATED WORK

The aforementioned conflicting requirements complicate the development of kinematically compatible two-legged exoskeleton. In general the exoskeleton design should be able to induce a torque on a specific human joint axis, meaning that the joint mechanisms should be rigidly connected and kinematically equivalent or not equivalent to the human body. Mechanisms that are kinematically equivalent (e.g. [1]) are compact and simple but can not fully compensate micro misalignments. Kinematically not equivalent mechanisms (e.g. [2]) can self-align to the Instantaneous Center of Rotation (ICR) of the anatomical joint but generally consist of a high number of mechanical joints and are therefore complex to actuate and require a larger installation space.

Fig. 1. CAD-design and passive prototype of the lower limb exoskeleton.

III. OWN APPROACH AND CONTRIBUTION

We presented a kinematically not equivalent joint mechanism for the hip, which consists of 5 revolute, 3 prismatic and 1 ball joint to self aligns the human-exoskeleton joint axes [3]. Additionally, Rolling Contact Joints (RCJ) which mimic the migration of the ICR and allow rotations around all anatomical joint axes were developed in [4] using a kinematic simulation to optimize the shape of the rolling elements. This simulation was also utilized to compare all joint mechanisms with existing devices from literature, indicating a comparable or better kinematic compatibility. The small installation space allows the integration of those mechanisms into the lower limb exoskeleton depicted in Fig. 1. The design includes 15 eccentric clamps to scale the device to users within a body height of $1.54\,\mathrm{m}$ to $1.86\,\mathrm{m}$ and includes four actuators to assist flexion/extension motions in all lower limb joints as well as hip abduction/adduction motions. The exoskeleton is flexible enough to allow activities of daily living and is able to create a maximum torque of $48\,\mathrm{Nm}$ at the hip, $15.7\,\mathrm{Nm}$ at the knee and $19.8\,\mathrm{Nm}$ at the ankle joint.

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A lower limb segment based control concept for exoskeletons with anti-gravity support

Martin Grimmer*[1], Kai Schmidt*[2,3], Jaime Duarte[2,3] Lukas Neuner[2], Gleb Koginov[2], and Robert Riener[2,3]

Abstract— **Lower limb exoskeletons can be used to withstand or act against gravity. Here we present a control idea that is able to scale the assistance torque as required and switch the assistance on during stance and off during swing.**

I. INTRODUCTION

Lower limb exoskeletons were developed to enable and assist walking for user groups with and without walking capabilities [1]. For users with walking capabilities, exoskeletons were designed to assist forward progression by injecting energy at the hip or the ankle joint [2]. In contrast, by assisting the hip and the knee extension, users could get assistance to withstand gravity in standing and walking, and to act against gravity in sit to stand transitions and when walking inclines or climbing stairs. This article will describe a control idea for such an assistance concept that has the capability to switch the assistance on and off during stance and swing, and to scale the assistance torque as required.

II. CONCEPT

To assist the human leg extensor muscles with an exoskeleton, a concept is required that includes sensor information about the users posture and/or the movement. We believe that the virtual leg length, the distance between the hip and the ankle joint, is a good measure to scale the assistance torque. It can be determined by inertial measurement units (IMUs), one at the thigh and one at the shank or an angle encoder at the knee. We propose two modes. The anti-gravity mode will help the user to resist or act against gravity. The with-gravity mode (changed by a switch) will support the user to slowly move with gravity (stand to sit). For initial experiments in sit to stand transitions the assistance torque was scaled based on the measured virtual leg length and the human knee torque of sit to stand transitions measured in previous experiments [3]. In the with-gravity mode the torque is further multiplied by a damping term based on the virtual leg (or knee angular) velocity. While sit to stand transitions only include standing, walking will additionally require a swing phase where the knee and hip extension assistance is turned off. To detect stance and swing phase, we investigated on an idea that is based on the angular velocity of lower limb segments. While a positive angular velocity (clockwise rotation compared to walking direction) should indicate stance, a counter-clockwise rotation of the segment should indicate swing. Further, the transitions in between can be used to detect heel-strike and toe-off. Two biological (thigh, shank) and two virtual (virtual leg, extended virtual leg, [4]) lower limb segments were evaluated on their reliability (just two sign changes of the angular velocity per stride) and the accuracy (offset in timing between sign change and ground reaction force based timing) of the virtual and biological segments for detecting both gait phases.

III. RESULTS AND DISCUSSION

Initial sit to stand experiments with the Myosuit (MyoSwiss) demonstrated that the assistance torque can be scaled based on the virtual leg length [3]. To evaluate the ideas for the stance and swing detection, walking experiments without exoskeleton were performed at different inclinations. The results show that the detection of the heel-strike, and thus stance phase, based on IMU angular velocity is possible for different segments when additional rule sets are included to deal with the signal noise of the IMUs. The biological shank segment had the least variability in accuracy. The heel-strike events of the shank and both virtual segment were slightly early (3.3% to 4.8% of the gait cycle) compared to the ground reaction force-based timing. Toe-off event timing showed more variability (9.0% too early to 7.3% too late) between the segments and changed with walking speed. Further work is required to improve the timing accuracy for the toe-off detection (swing).

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Simultaneous and Proportional Myoelectric Control of Hand Prostheses - Evaluation in Daily Life

Janne M. Hahne[1,*], Meike A. Schweisfurth[1,2], Mario Koppe[1,3], Dario Farina[1,4], Arndt F. Schilling[1]

***Abstract*— Conventional hand prostheses only allow to control a single degree of freedom (DOF) at a time using two electromyographic (EMG) signals from the muscles of the residual limb. This is cumbersome and limits the benefit of additional DOFs offered by modern hand prostheses. We implemented a control approach that allows for simultaneous and proportional control of two degrees of freedom based on linear regression (LR). We first demonstrated the robustness of this system on five prosthetic end users in challenging prosthetic tasks in the laboratory. Then, one transradial user tested the approach in a longitudinal two-months trial in daily life. The LR control approach outperformed conventional control in most conditions and was stable over time in daily life without retraining.**

I. Motivation and Problem Definition

Losing a hand has a dramatic impact on a persons life. Hand prostheses help the person to conduct activities of daily living with less restrictions. They are typically controlled with electromyographic signals, acquired from the muscles in the residual limb by electrodes integrated into the prosthetic socket [1] . With conventional techniques it is only possible to control one function at a time and cumbersome mode-switching techniques are used to control additional functions.

II. Related Work

Recently classification-based systems have become commercially available that allow to directly access all functions directly, but they still allow to control only one function at a time [2]. Contrary to this, in regression a continuous estimation of the activity in multiple DOFs is made independently. This allows for fluent transitions between two motions and simultaneous activations of multiple DOFs. Moreover, the velocity in each simultaneously activated motion can be controlled independently. Regression-based approaches have been investigated in several research studies [3]–[5], but its practical applicability in daily life was yet to be demonstrated.

III. Own Approach and Contribution

We implemented a controller in an embedded system based on linear regression that allows to control the two DOFs open/close and rotation of a commercially available hand prosthesis simultaneously. We had recently demonstrated the robustness of this LR approach on five prosthetic end-users during challenging prosthetic tasks in the laboratory [6]. In the current study, we evaluated the system on one transradial prosthetic user in daily life over a duration of two moths. The LR approach performed stable over a longitudinal use in daily life without retraining of the regression model. Simultaneous and proportional LR control outperformed the system the user had been wearing usually in daily life in three functional outcome metrics (Box-And-Blocks Test, Clothespin-Relocation Test, and SHAP Test, Fig.1/2). These results suggest an advantage of LR control over conventional prosthesis control.

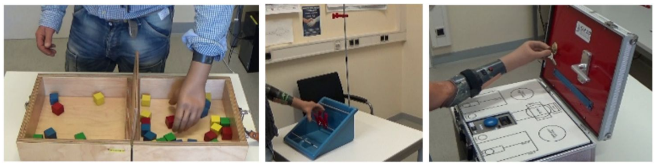

Fig. 1. Evaluation of the simultaneous and proportional LR control in functional tests. (l.): Box-And-Blocks Test. (m.): Clothespin-Relocation Test. (r.): SHAP test (one example).

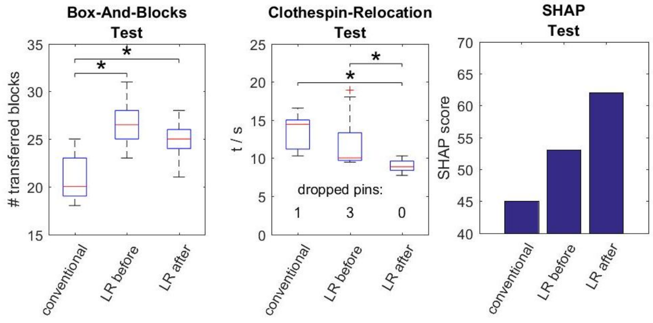

Fig. 2. Results of the functional tests. Box-And-Blocks Test (l.), Clothespin-Relocation Test (m.) and SHAP Test (r.). All tests were conducted with the conventional control owned by the participant (conventional) and the linear regression-based control (LR before) in the beginning of the study. The linear regression control was evaluated a second time after the 8-week home trial (LR after).

Acknowledgment

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Online planning and control of ball throwing by the humanoid robot COMAN and validation exploiting VR in rehabilitation scenarios with ataxia patients

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In the long run, humanoid robots might become interesting for applications in rehabilitation training. As a first step toward such scenarios, we tested the usability of the humanoid robot COMAN (Italian Institute of Technology) for a physiotherapeutical training scenario that is frequently used for coordination training. Due to the limited degree of robustness of the available humanoid robot systems, development of relevant control system with the patient in-the-loop is a strong challenge. Patients that are affected significantly by movement disorders typically show impaired motor behavior, which in turn requires highly reliable robots to interact with. To deal with this problem, we embedded a physics-based simulation of the humanoid robot COMAN as part of an interactive Virtual Reality (VR) environment that is suitable for use by motor-impaired patients. This allowed us to develop optimized training scenarios for ataxia patients without any risks, and to provide a technically highly robust simulated interactive robot system while embedding realistic real-time controllers. We tested this system and obtained feedback from cerebellar ataxia patients on its usability.

Training scenario: Cerebellar ataxia patients benefit substantially from coordinative motor training in everyday-related situations [1]. Administering such training with sufficient intensity is a substantial problem for cost-efficient rehabilitation. One effective exercise for coordination training is throwing and catching of balls (juggling with two people). In our scenario, one person was replaced by the humanoid robot COMAN (respectively its simulation). Participants had to catch ball thrown by the robot. Throwing style and variability was adjusted in a manner that was suited for the skill level of the individual patients.

System architecture: The overall system was implemented in a unified software framework that integrates real-time control (OROCOS), the UNITY game engine, and the Gazebo physics simulator of the COMAN robot (Fig. 1). A Virtual Reality (VR) environment was implemented using the HTC Vive system, which combined a Head Mounted Display (HMD) with two motion trackers with a sampling frequency of 90 Hz. The system update time via the RSB communicator was about 1 ms and the controller running with an update time of 1 ms. The actions of the patient are interpreted using the SteamVR plugin, running with approximately 5 ms latency.

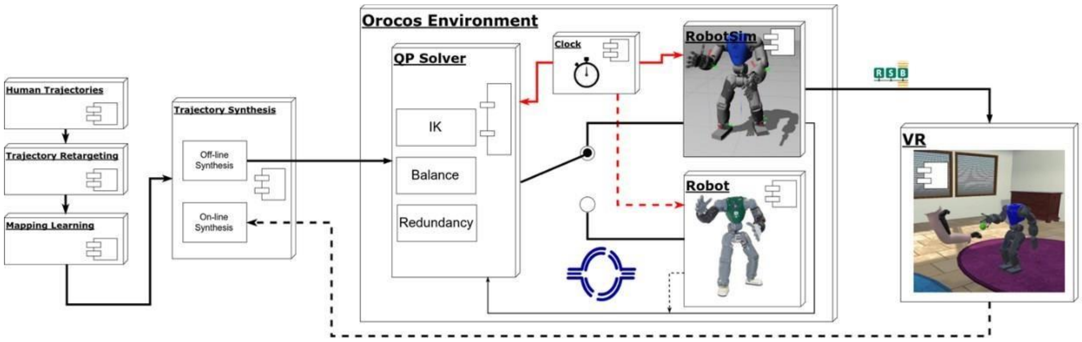

Fig. 1: System architecture embedded using unifying OROCOS real-time software environment.

Participants had to catch balls thrown by the simulated robot. In addition, experiments with a human avatar were also realized. Hand closing of participants was simulated by a trigger button press on the handheld controller of the VIVE system, which was also used to track the hand position. The arm movements of the robot were derived from real human arm movements, implementing an online planning algorithm for arm movements that was based on dynamic movement primitives that were learned from (retargeted) real human ball throwing trajectories using anechoic demixing [2].

The online-planned hand trajectories were used as input for the full-body movement controller of the robot, which was implemented as part of the OROCOS software environment [2]. Balance control was realized exploiting a Stack-of-Tasks approach defining maintenance of balance as task with highest priority. The lowest priority task is the realization of the posture of the right arm and torso orientation, eliminating redundancies.

Results: Experiments with a human avatar and healthy subjects show that ball catching is strongly dependent on the virtual ball trajectory, but also systematically influenced by body cues that indicate the throwing direction. Participants achieved a high level of spatial and temporal accuracy during the catching task and reported high immersion scores, suggesting a high degree of acceptance of the VR environment. Pilot experiments with ataxia patients show that they can successfully use the developed interactive training system and show motor learning that seems to transfer to other untrained coordinative tasks (walking). Patients gave very positive user feedback about immersion and adaptability of the training system. They were able to catch successfully the balls thrown by the virtual robot, including all relevant physical constraints. The provided user feedback by additional visual cues and automatically generated verbal feedback was highly appreciated by the patients.

Fig. 2: Throwing sequence in VR generated by GAZEBO physics simulator of the robot.

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Functional Outcome Measurements: task decomposition as a new approach to assess the performance

Jeremy Mouchoux M.Sc.[1], Prof. Dr. Med. Arndt Schilling[1] and Marko Markovic Ph.D.[1]

Abstract— **Functional outcome measurements aim to measure the performance of the subject in a reproduction of an activity of daily living such as grasping an object. While these tests are used by researchers to assess new controls of the prosthesis, they can contain a bias by including phases which do not require a control of the prosthesis. The work presented here studies the decomposition of the trial in several phases to assess precise impact of the prosthesis control on the overall performance.**

Functional Outcome Measurement, Prosthesis Control, Box and Blocks

I. MOTIVATION AND PROBLEM DEFINITION

Functional outcome measurements (FOMs) for upper limb prostheses are a growing research topic. These tests reproduce tasks from activities of daily living to assess the capability of retaining normal arm function of a person with upper limb deficiency. They are used by both research as well as the prosthetic community. A wide variety of such tests is currently available, assessing different aspects of the prosthesis control. For example the Southampton hand assessment procedure (SHAP) [1] focuses on fine grasp activity while the Clothespin Relocation Test [2] assess the dexterous manipulation of objects. In many of these tests, task completion time is used as a principal performance outcome. Even the simplest object manipulation task can be decomposed in different sub-phases such as reaching, preshaping, grasping, carrying, manipulating, releasing. Each of these phases contribute to the overall task execution time, however their significance in measuring the prosthesis performance varies significantly. For example, in transradial amputees, the reaching phase does not require employment of any specific prosthesis skill or control strategy, the user moves the unaffected arm joints in order to reach out for the object. Changes in the speed of such movements can greatly influence overall FOM performance. If the user has trouble in controlling the prosthesis, he/she could choose to compensate for the lost time by accelerating exactly those phases of the task that do not require actuation of the prosthesis functions (reaching for an object, carrying an object). This would lead to masking of deficits of the overall prosthesis control. Therefore, measuring only the total task execution time does not allow a complete understanding of the assessed system as potential benefits of a better control algorithm may be diluted by the phases without active prosthesis control. We advertise a novel approach in which we utilize force, position and myoelectric sensors that are embedded in the prosthesis in order to automatically detect and quantify different task phases and their contribution to the overall task execution time.

II. RELATED WORK

In order to improve the functional outcome measurements for prosthesis control, the research community frequently modifies already existing standardized and clinically validated tests. For example in [3], the authors have modified the standard Box and Blocks test to focus on the quality of the reach and grasp movement by sorting the blocks to transport. In a further development [4] a constraint for the release of the blocks was added in order to study the quality of the releasing action. Similarly, the Clothespin Relocation test has been modified in [5] by adding a maximum aperture threshold on the clothespins in order to assess the fine force regulation during the manipulation task.

III. OWN APPROACH AND CONTRIBUTION

The novel task decomposition was implemented by analyzing the data acquired from the sensors embedded in the prosthesis to classify the following task phases: reaching, preshaping grasping, transporting, manipulating and releasing. Reaching is the time spent with no actuation of the prosthesis without object in the hand, preshaping is the time spent actuating the prosthesis without object and grasping is the action to close the hand resulting to an object grasped, detected as a non-null force applied by the hand. On the other hand, transporting is the time spent with an object in the hand of the prosthesis without any actuation, manipulation is the action to actuate the prosthesis with object and releasing is the action to open the hand leading to a null force applied by the hand. We have evaluated the novel task decomposition approach in two different experimental setups using clinically validated box and blocks reallocation task for evaluating core prosthesis function. In this test, we used a Michelangelo hand prosthesis, with wrist rotator and wrist flexor, and with position encoders and a single force transducer placed at the base of the thumb. The data from the prosthesis was acquired over a Bluetooth interface at 100 Hz. Eight electromyogram (EMG) electrodes placed equidistantly around wrist flexor and extensor muscles were used to acquire muscle contraction patterns of the subjects. These patterns were then classified by the linear discriminant analysis (LDA) classifier in four classes plus rest. The first experiment compared the decomposition of the task performed by one subject with an LDA classifier using 0% of added error against 10% added

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error. With 0% of added error, the subject was transporting one block in average in 3.55s ±0.53s, with 1.49s ±0.28s for reaching, 0.42s ±0.19s for preshaping, 0.70s ±0.04s for the grasping, 0.40sec ±0.19s for transporting and 0.50s ±0.06s for releasing. With 10% of added error, the total time per block remained the same in average (3.49s ±0.65s per block). This was caused by a reduction in time spent to reach the block(1.41s ±0.52s) and transport it (0.31s ±0.15s), which was the reaction to prolonged time spent in block preshaping, grasping and releasing, and (respectively 0.44s ±0.17s, 0.73s ±0.12s and 0.50 ±0.05s), as we have initially hypothesized. Our results demonstrate that there is a significant influence of a transport phase on the overall score achieved in the box and blocks test. By dividing the task into phases, we were able to explain the initially counterintuitive result, that is, that the subject with perturbed control (10% added noise) managed to achieve better performance than with unperturbed control (0% added noise). In conclusion, our approach expands the understanding of contemporary FOMs and enables better interpretation of their results.

ACKNOWLEDGMENT

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Template-based control of prosthetic feet

Amirreza Naseri[1], Martin Grimmer[2], Andre Seyfarth[2] and Maziar Ahmad Sharbafi[2]

***Abstract*— In this paper, we present a novel template model-based control approach for control of ankle prosthesis. This method which is called FMCA (force modulated compliant ankle) employs ground reaction force to modulate ankle joint impedance. Inspired by our previous studies and also findings in human gaits, we know that leg force could play an important role in legged locomotion control. Here, we employed this method first on a simulation model using a neuromuscular model of human walking and then on a prosthetic foot. We showed that the same controller can assist subjects to generate normal gait patterns in walking at different speeds. Using template models which are resulted from an abstraction of complex biological models provide one simple controller which be used at different walking conditions.**

I. MOTIVATION AND PROBLEM DEFINITION

Generating a universal bioinspired control approach to assist healthy or impaired people in different gait conditions (e.g., speed) is challenging in gait assistance. In contrary to trajectory-based approaches [1], model-based methods [2] could potentially address the applicability of the controller in different situations. Among them, neuromuscular models [3] are useful tools for approximating human behavior to provide the required torque in assistive devices. The main barrier in using such models is their complexity which hinders researchers to apply them on systems with few degrees of freedom such as ankle prostheses. To resolve this issue, in this paper, we introduce FMCA (force modulated compliant ankle) as a template based control method to control ankle prosthesis. The simulation and (pilot) experimental results support the functionality and generalization property of this approach. Here, we considered three different motion speeds which can be controlled by a unique controller.

II. RELATED WORK

Regarding higher energy consumption and slower self-selected speeds reported by transtibial amputees using passive Ankle devices, scholars realized that an active prosthesis needs to generate positive net work over a gait cycle. Thus, several control structures produced for these type of prosthesis like a quasi-stiffness control [4] and minimum jerk swing control [5]. An Impedance control which uses piecewise impedance function to mimic normal gait pattern is one of the most common control schemes in powered prosthesis [6], [2]. The impedance function needs to alter to adapt to the environment (e.g., terrains), to cope with undesired disturbances or to change gait condition (e.g., speed). One bioinspired approach is using neuromuscular reflex control [2] for predicting the dynamics of human gait to adapt the prosthesis controller accordingly. In such model-based control methods, human musculoskeletal model and the neural (reflex based) control [2] can be used instead of following predefined joints torques (or positions). Although the ability to predict human reaction enables this controller to be adaptive while needed, the proposed model is too complex to be preferred to simple trajectory-based approaches.

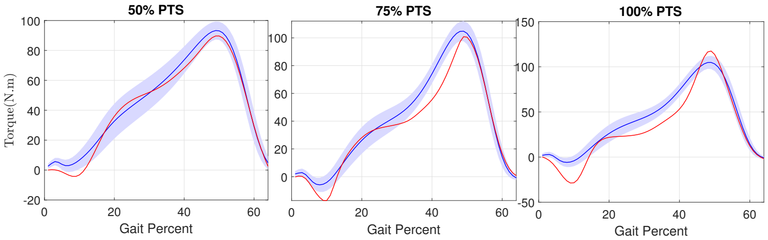

Fig. 1. Normal Torque(blue) and Estimated Torque(red) in 50,75 and 100 percent of preferred speed

From another perspective, abstraction is a useful tool in simplifying complex model (termed Anchor models) to the template level [7]. With biomechanical template models, we can describe some significant features of locomotion with simple physical systems (e.g., Spring mass system) [7]. In [8] we introduces the FMCH (force modulated compliant hip) model as a template for posture control. In this method, the leg fore is utilized to adjust hip compliance. This approach was successfully implemented on LOPES II exoskeleton resulting in metabolic cost reduction in human walking [9]. Using leg force feedback in a simple control architecture to tune the stiffness of linear spring at hip joint could be also used for controlling other joint. In this paper this sensory information is utilized to control ankle joint impedance in a prosthetic foot.

III. OWN APPROACH AND CONTRIBUTION

In the here presented FMCA method, the ankle torque is approximated by the ankle angle and angular velocity (as a variable impedance) which is modulated by the leg force (GRF). This model should predict required ankle torque at different speeds. The dependency of joint torques and ground reaction force at different speeds [10], [11], [12] support the idea of using GRF as a useful sensory signal which can be used to predict the required joint torques needless to

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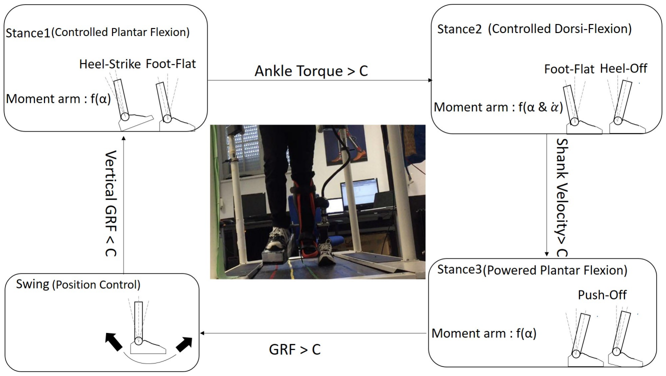

Fig. 2. FMCA Hybrid System Implemented on Spring-Active Prosthesis. The ankle angle and angular speed are shown by α and $\dot{\alpha}$, C= threshold.

measure the gait speed. In this study first, we use human walking data at three different speeds from [13]. Defining PTS as the preferred transition speed between walking and running, 50%PTS, 75%PTS, and 100%PTS are utilized as a normalization tool (for comparing different human subjects) for slow, moderate and fast walking. For investigating the validity of the FMCA approach, first, we predict human ankle torque based on the measured data. By building a simple model of the foot as a spring and damper, the GRF tuned the stiffness and damping coefficients with a similar formulation for different walking speeds. For this, we estimate the moment arm at different speed by using ankle angle and angular velocity. Then by using this moment arm and multiplying to GRF, ankle torque will be achieved. Fig. 1 shows the comparison between the measured ankle torque and the approximation using FMCA.

The next step is implementing the proposed control approach on the prosthesis. We divided the stance phase into three states. Fig. 2 shows a finite state machine with a predefined threshold (C) for a transition between these three states. In each state of the stance phase, the moment arm is determined based on the ankle angle α or angular velocity $\dot{\alpha}$. The most important phase for assistance is the push-off phase which happens in the third state.

In order to implement FMCA on the prosthetic foot, we used GRF measured by an instrumented treadmill. We applied the method on the powered ankle prosthesis developed by Spring-Active. As shown in Fig. 2 the experiment was on a healthy subject while human ankle joint was bypassed and the second leg height was increased by additional foam. The experimental results are shown in Fig.3. It is observed that the ankle angle, GRF, and ankle torques are comparable with those of normal walking (from [13]).

IV. CONCLUSION

In this study, we showed that a template-based control can generate human-like ankle torque at a different speed. This method was successfully implemented on an ankle prosthetic foot. generating he ranges and patterns for the measured variables (GRF, ankle torque, and ankle angle) are similar to reported data for level ground walking at normal

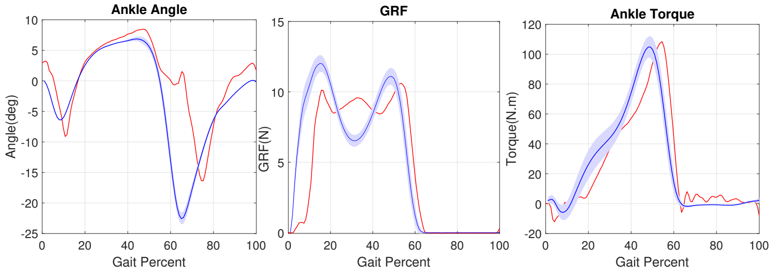

Fig. 3. Ankle Angle, GRF and Ankle Torque of Prosthetic Foot Normal (blue) , Spring-Active(red)

speed (75%PTS). This study is the first step in developing a template based controller for prostheses and is in line with our previous findings on exoskeletons [9]. This is a new approach in control of assistive devices which is founded on top of human-inspired control modeling.

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Textile-Based Soft Wearable Actuators

John Nassour[1] and Fred Hamker[1]

***Abstract*—The usage of textile-based soft materials for building robots overcomes the problem of rigid contacts with the human body. How can robots be efficient and embedded inside what we wear at the same time? We investigate two types of textile-based wearable actuators: an enfolded inflatable textile actuator and an online programmable actuator. The fist shows a significant performance in assisting human motion (hand and elbow). The second shows a flexible and versatile behaviours: bending, twisting, elongation. It can also be used as two sections to provide more complex behaviours. The proposed actuators provide insights for wearable assistive clothing.**

I. MOTIVATION AND PROBLEM DEFINITION

Soft actuators has been widely accepted to assist human motion thanks to their friendly contact with the human body, lightweight, and less constraints than their rigid counterparts. Soft wearable robots are complementary to rigid ones [1]. The amount of force, torque, and velocity delivered by soft robots remains not to be in equivalence with that delivered by rigid robots [2]. A wide range of motions such as bending, expanding and twisting has been obtained by introducing oblique structures in silicon-based soft actuators. However, this mechanical programming allows an actuator to generate one single behaviour while inflated. This abstract addresses two challenges in soft wearable actuators: high force actuator and programmable actuator for versatile behaviour.

II. RELATED WORK

Soft pneumatic actuators based on folded tubes have been investigated many times previously [3, 4]. Textile-based soft actuators has been recently addressed through several designs to assist human movements [5–9]. The pneumatic interference actuator PIA [10] was adopted in [6, 11], while an improved version of the PIA was presented by [12]. A recent work by [5] shows that a sequence of inflatable pillows may increase workers bicep lifting capacity. However, as each pillow has a separated inlet pneumatic tube, the device becomes bulky with an increased number of pillow. The difference in mechanical proprieties of two textile materials exhibits bending behaviour in [6]. The above mentioned studies show a large range of textile-based actuators design, each targets a particular movement or a joint. How to build a generic textile-based actuator that can assist human movements at different scales (e.g., finger and elbow)?

III. OWN APPROACH AND CONTRIBUTION

We proposed two designs of textile actuators, see Fig. 1. Each actuator is made of two parts: an inflatable tube and housing. Tubes are made of a bladder (TPU) wrapped by textile. The housing of the actuator is made of fabric or ribbon sawed to form successive parallel channels which hosts the enfolded tube. The tube is inserted in the parallel channels of the housing by flowing a zigzag path. Therefore, each part of the tube hosted by a channel forms an inflatable segment that will laterally push the neighbouring segments when being inflated. In the first design (see Fig. 1(a) to (g)) the housing parallel channels are glued and sewed on a textile ribbon. When the tube is inflated, the actuator will bend to one side. This actuator was made at different sizes to actuate fingers and elbow. We provide an analytical model of the actuator's torque as a function of geometry and air pressure. Its significant performance is presented on Fig. 1(b)-(f). In the second design (see Fig. 1(h) and (i)), four strings are attached to the tip of the actuator and travelling through its longitudinal axis to the fixed side where they are pulled with different tension forces [13]. The applied forces on all strings define the actuator behaviour

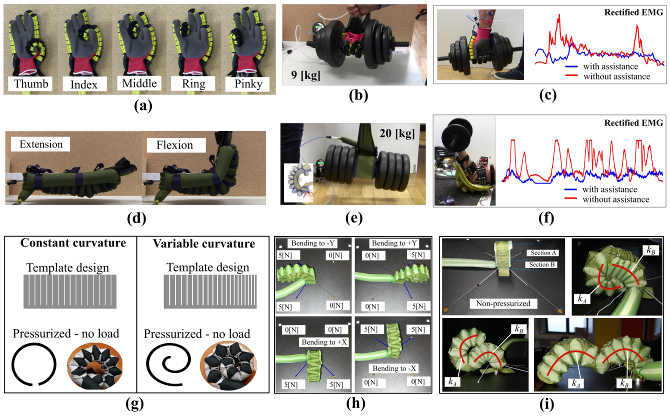

Fig. 1: Soft robots developed at the TU Chemnitz. (a) The wearable active glove uses folded textile actuators, each finger can be controlled separately. (b) The glove shows high power in holding 9 [kg] weight bar. (c) The glove assistance during weight bar lifting experiment measured by EMG. (d) The elbow exosuit doing flexion and extension. (e) The flexor actuator shows high performance in holding 20 [kg] weight bar. (f) A wearable elbow device assists human in lifting 5 [kg] during rhythmic flexion/extension [14]. (g) The folded inflatable actuator with constant and programmable curvatures. (h) Online programming of behaviour of a soft textile inflatable actuator. The behaviour is programmable by four pulling strings. (i) Two sections of the actuator allows it to show different bending behaviours simultaneously (one per section). Each section uses a separated four pulling strings, while both sections use a the same inflatable textile tube.

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when inflated. Bending in different directions, twisting, and elongation behaviours were generated online by varying the strings pulling forces and the air pressure of the actuator. The kinematic model of the actuator is also presented using piecewise constant curvature (PCC) method. The actuator can be designed with multiple sections and therefore it can exhibit more complex behaviours. The dynamic model of the actuator and its integration in wearable application will be addressed in our future work.

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Magnetometer-free Inertial Motion Capture System with Visual Odometry

Bertram Taetz[1], Atabak Nejadfard[2], Patrick Vonwirth[3], Karsten Berns[4] and Gabriele Bleser[5]

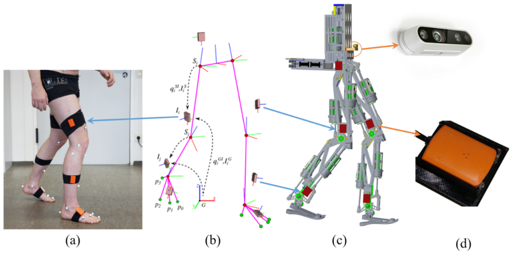
Abstract— **We propose a wearable sensory system comprising inertial measurement units, pressure insoles and a stereo camera. The planned hardware system is designed to be easily mountable on both an exoskeleton and a human. The planned software system delivers online 3D kinematics and ground contacts as well as a recorded mapping of the surroundings. Kinematics and map will be registered with each other in a post-processing step. Our objective is to develop this hardware and software platform for both exoskeleton and bipedal robot benchmarking.**

I. MOTIVATION AND PROBLEM DEFINITION

This project has just started and the aim of this extended abstract is to introduce the system design and the involved components and to communicate the intended availability of the system for the community.

Motion data acquisition is an enabling technology for benchmarking human and robot movements. The majority of motion capture systems is limited to data acquisition in restricted and structured environments, e.g. due to the tracking volume provided by camera based setups. Consequently, daily human activities cannot be recorded in their natural settings [1]. To overcome this, a platform should be designed that can acquire motions such as handling processes in a factory [2], driving a car, skiing [3], or simply walking in rough outdoor terrain. In these scenarios, the environment is unstructured and, therefore, the benchmarking platform not only needs to record the movement of the biped or human, but the perception of the surroundings with respect to the body is also important for analysis purposes.

We aim to develop an integrated wearable sensory platform for bipedal systems. Inertial measurement units (IMUs), see Fig. 1(a), are gaining popularity for in-field human motion tracking. Applications range from character animation and sports analytics over ergonomic assessments and workflow analysis to medical applications, such as gait analysis. IMUs are portable and can be installed on segments of a human body or a robot. There are commercially available systems for human motion tracking, for instance Xsens [4], [5], which can simplify the integration effort of a benchmarking platform. For the proposed scenarios, current inertial systems, however, have two main downsides that we will address:



(a) (b) (c) (d)

Fig. 1. Proposed sensory platform for the human and bipedal robot benchmarking (a) an inertial motion capture device is mounted on the leg. The optical markers on the body are used for validation of the inertial system using optical motion capture. (b) The skeletal information for 3D magnetometer-free posture reconstruction. (c) The IMU units mounted on the bipedal robot. The miniature stereo camera unit is installed on the trunk for visual odometry and better 3D mapping of the environment.

1) They cannot measure the surroundings and do typically also show (position) measurement drifts over time [1].
2) They typically use magnetic IMUs (MIMUs). The magnetometer data is utilized to obtain an observable orientation via a local measurement of the earth magnetic field. In the presence of artificial magnetic fields, e.g. nearby metallic surfaces or electric current, as could be produced by robots, this introduces errors.

This considerably limits current commercial IMU systems for motion analysis of human-robot systems.

II. RELATED WORK

We build upon recent advances in magnetometer-free inertial body motion capture [6], [7]. The respective method does not need magnetic information in any phase of the calibration or tracking and fuses the inertial data jointly with the complete body configuration, see Fig. 1(b). It delivers drift-free 3D kinematics in a body aligned coordinate system of the skeleton, i.e. there is no orientation drift between segments, during motion. Moreover, the only drift with respect to an external (global) coordinate system is with respect to the heading direction, which is addressed in 2). Visual odometry estimation and simultaneous localization and mapping (SLAM) of the environment, on the other hand, made considerable progress within the last years. Recent systems provide odometry information from an integrated miniature stereo camera system like ZED [8] or RealSense [9], in an embedded computer, see Fig. 1(d). This allows for 3D position and orientation estimation, which gives complementary information to the purely inertial system. The camera systems also contain an embedded IMU and can be

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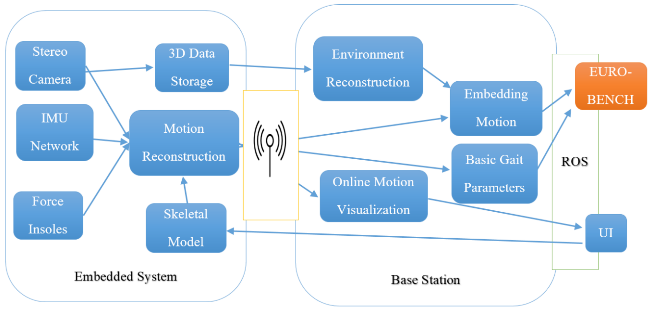

Fig. 2. Software structure and information flow.

mounted on a robot or human.

Further, online readable pressure insoles, like [10], [11], [12], allow for accurate measurements of the ground contact characteristics and, thus, enable to measure ground contacts in a mobile setting and unstructured terrain.

Finally, a currently developed bipedal robot [13], see Fig. 1(c), plays an important role in the evaluation of the proposed benchmarking system, in particular for testing the effects of different disturbances on the accuracy and communication stability on a robotic system. So far one leg of the robot dubbed as compliant robotic leg (CARL) is fully tested and evaluated. CARL consists of five series elastic actuators [14] that generate undesirable magnetic interferences that we have already coped with during the development of the mechatronics.

III. PROPOSED APPROACH AND PLANNED CONTRIBUTION

A block diagram illustrating the information flow within the proposed software architecture is given in Fig. 2. Our proposed sensory system will deliver real-time motion capture data of bipedal systems. The motion capture data will be evaluated and tested using optical motion capture technology to quantify the error in the kinematic data.

Our hypothesis is that stochastically fusing the visual odometry and pressure information with the information from the inertial system will considerably reduce or eliminate the amount of error in the heading drift; however, visual odometry and mapping has to be tested meticulously against the undesirable effects of jerky movements and oscillations especially in the robotic systems, which might cause drift in visual odometry system. We will also study the behavior of the inertial motion capture system when being mounted on a robot and investigate the level of magnetic interference not only on the magnetometers, but also on the circuitry and wireless communication of the IMU network. We will test the latency between visual odometry, IMU and pressure data to evaluate the precision of the sensory information and posture reconstruction. All the sensory information will be integrated into one software package developed in Finroc [15] and ROS [16]. The software will provide real-time visualization of the kinematics and foot ground contacts. The 3D reconstruction of the environment is provided in a post-processing phase when the recorded point cloud in the embedded computer is retrieved. All the major sensory components such as inertial motion capture system, miniature stereo vision, and wireless pressure sensor are available commercially. However, the full integration of these sensory systems in one platform can enable the already existing commercial entities to extend their product line. Two platforms will be provided to Eurobench facilities for human and robotic benchmarking [17].

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SoftHand Pro:
a Robust and Adaptive Bionic Hand to Enable Physical Interaction

Cristina Piazza[1], Giorgio Grioli[2], Antonio Bicchi[1,2] and Manuel G. Catalano[2]

***Abstract*— The loss of an upper limb is a major trauma which affects both the personal and the social dimensions of an individual. Only solutions capable to properly balance functional an structural anthropomorphism can really restore the quality of life of people with limb loss. Nowadays, state of the art of prosthetic hands is divided between very simple hook-like systems, and more advanced solutions, that try to match the functions of human hand at the cost of sever lack in intuitiveness and reliability. In this talk we present the last evolution of the SoftHand Pro, a soft multi-digit prosthetic hand in which structural and functional anthropomorphism are obtained thanks to the fruitful combination of soft robotics technologies and sensory-motor synergies. We introduce the new design and discuss outcomes coming from its use in the context of the Cybathlon Experience 2018, highlighting how a soft and adaptive design help the user in the execution of the proposed daily life activites.**

Fig. 1. A user holding a phone with the new version of the SoftHand Pro.

I. INTRODUCTION

Hands represent the main interface of humans with the world which they manipulate and the perceptual tools for sensing the environment. One of the challenges of modern technology is try to replace the structure and functionalities of the human hand in a robotic aid which enable persons with upper limb loss to effectively restore their quality of life. Moreover, the support of a reliable and more natural prosthetic aid can play a critical role in psychological well-being as well as social acceptance. State of art of modern hand prosthesis is rich of advanced prototypes, which usually offer a broader set of movement capabilities, with the possibility to control up to 4 or 5 motors independently, achieving several different postures [1], but unfortunately not so easy to control. This issue often leads on the device abandonment or on the choice to use simpler solutions as body powered hooks [2]. Moreover, these polyarticular myoelectric prosthesis cannot replicate exactly the complex architecture of bones, joints, muscles and ligaments of the human hand. Indeed, to limit the system technical complexity, they inevitably require a loss in terms of number of degrees of freedom and substructures included. In the recent past our group introduced the SoftHand Pro, a soft multi-digit prosthetic hand in which structural and functional anthropomorphism are obtained thanks to the fruitful combination of soft robotics technologies and sensory-motor synergies. The resulting system, while still keeping an aesthetically and functional biomimetic design, is capable to perform a useful subset of the functions of human hands. In this talk we present the last evolution of the SoftHand Pro and discuss outcomes coming from its use in the context of the Cybathlon Experience 2018, highlighting how a soft and adaptive design help the user in the execution of daily life activites.

II. THE SOFTHAND PRO

The SoftHand Pro is a 19 DOF anthropomorphic hand that combines intuitiveness, adaptivity and robustness. The shape-morphing artificial hand we propose is the result of a scientifically principled biomimetic combination of soft ”muscles”, elastic ”ligaments”, flexible ”tendons”, articular ”joints” and rigid ”bones” with kinaesthetic and cutaneous ”receptors” inspired by the principles that underpin the human architecture and its sensorymotor apparatus and realized through contemporary technologies such as soft robotics. Thanks to the use of a single motor to activate all the joints in a coordinated ”synergistic” fashion, the hand affords qualities such as simple control and adaptability to the grasp pattern. Indeed, the SoftHand Pro can be myoelectrically-controlled using only two surface electromyography (EMG) electrodes. The preliminary prototype of the SoftHand Pro was tested with individuals with limb loss [3] with encouraging results. Recently we developed a new version of the hand, showed in Fig.1. The shape of the hand, and consequently the mechanical and electronic components, were designed in order to obtain a more human-like and smaller shape,

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Fig. 2. SoftHand Pro at the Cybathlon Experience 2018. Tasks: (a) Clean Up, (b) Laundry , (c) Home Improvement and (d) Wire Loop.

Fig. 3. The photo-sequence presents our strategy adopted to grasp a mug. The SoftHand Pro can change its shape according with the environmental constraints, and we exploited this feature to get a different closure shape.

TABLE I

RESULTS OF THE SOFTHAND PRO TEAM AT CYBATHLON EXPERIENCE 2018

	Race	Clean Up	Laundry	Home Improvement	Wire Loop	TOTAL SCORE	TOTAL TIME (s)
DAY 1	1	101	104	0	0	205	-
	2	0	104	110	125	339	290
DAY 2	1	0	104	110	125	339	276
	2	101	104	110	125	440	360
DAY 3	1	101	0	0	0	101	89
	2	101	104	110	125	440	323

together with a lighter weigth. Moreover, the new release of the SoftHand Pro was provided with a customized cosmetic glove in silicone, to ensure a good and stable grasp.

III. THE CYBATHLON EXPERIENCE: REHACARE 2018

We explored the advantages of our approach in the context of Cybathlon Experience 2018, where we partecipate as SoftHand Pro team. Our pilot (38, Female) has congenital malformation at the trans-radial level in the left hand. She is an user of cosmetic prostheses, and occasional user of myoelectric prostheses. The four participant teams were asked to compete two times per day. The race consisted in complete four tasks in a maximum time of 6 minutes. The proposed tasks varying from abstract, aimed to challenge different aspects of the Pilot's control and prosthetic technology itself, to practical tasks mimicking ADLs, aimed at testing prosthesis functionality in real-world situations. Some examples are reported in Fig. 2. The results (see Table I) achieved by the SoftHand Pro team are promising and show the effectivness of the system. Only in one race (day 3 - race 1) she was able to complete only the first task because of a device technical problem. In two tracks our pilot was able to complete all the four tasks in less than 6 minutes, highlighting that a proper trade-off between form a function can offer good performance and robustness. Soft-robotics technologies and the hand adaptability offer the possibility to execute daily living task in a more natural way. Exploiting these features the user is able to perform different grips with unconventional approach, as through imposed constraints. Fig. 3 shows the strategies adopted to grasp and move a mug. The hand resilience plays a key role to perform more work-oriented tasks, as hammering a nail.

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The KIT Prosthetic Hand

Pascal Weiner, Julia Starke, Samuel Rader, Felix Hundhausen and Tamim Asfour

Abstract— **Acceptance of myoelectric hand prostheses depends heavily on their ease of use. Both training with a new prosthetic device as well as grasping in daily life should impose a low cognitive burden and are experienced as fast and fluid. We propose a novel prosthesis design to foster these goals by implementing an adaptive force distributing mechanism as well as an embedded system providing the basis for semi-autonomous control.**

I. MOTIVATION AND PROBLEM DEFINITION

Myoelectric hand prostheses can enable amputees to regain autonomy and hence significantly improve the quality of life for prosthesis users. But despite advancements in both prosthetic hand hardware as well as control strategies, around $50\,\%$ of users abandon their prosthetic device [1]. Two of the main reasons for device abandonment are the high training effort and the cognitive burden on the user during grasp execution. With direct myoelectric control, a prosthesis user has to concentrate on the task of grasping for both positioning and orienting the prosthesis with respect to the object as well as selecting the appropriate grasp, all by generating the right myoelectric patterns.

II. RELATED WORK

Mechanical and electrical design of myoelectric hand prostheses is a challenging task in terms of space constraints, weight as well as achieving a human-like appearance. The mechanical design and actuation of commercially available myoelectric prosthetic hands is presented in [2]. In research, the design of hand prosthesis is driven by the development of novel actuation mechanisms as well as an increasing interest in sensorization and semi-autonomous control. The MANUS-Hand [3] utilizes a set of only three motors for the actuation of thumb and finger movements as well as wrist rotation. Force sensors allow to control the grasp strength. Different underactuation configurations have been for exam explored with the SmartHand [4], SSSA-MyHand [5] and the Vanderbilt hand [6] to name a few. Most of these prostheses contain a lean embedded system for basic control.

Adaptive underactuation mechanisms like the TUAT/Karlsruhe mechanism [7] allow the actuation of all fingers with one motor. A different mechanism actuating all fingers is implemented in the SoftHand-ProD prosthesis [8].

Fig. 1. The KIT Prosthetic Hand. The underactuation mechanism allows the fingers to adapt to the shape of the object.

III. OWN APPROACH AND CONTRIBUTION

In this work we present the development of our intelligent and configurable hand prosthesis, the KIT Prosthetic Hand. The prosthesis is actuated by two motor-gear units in the palm for finger and thumb flexion via tendons. Extension of the fingers and thumb is realized by torsion springs inside of the finger joints. The fingers are connected to the motor through an adaptive force-distributing mechanism which distributes the motor torque. If one or multiple fingers are blocked, the others are still able to close. This allows the fingers to wrap around arbitrarily shaped objects.

An embedded system with a powerful embedded processor is integrated into the palm. It is connected to various sensors including a camera in the palm, a distance sensor and an IMU. Feedback to the user is provided by means of a display in the back of the hand. The embedded system provides the basis for the implementation of semi-autonomous control schemes aimed at reducing the cognitive burden of the user while controlling the prosthesis and simplify training. The hand prosthesis design is based on a scalable model that

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allows adaptation of the hand and finger dimensions to match the appearance of the prosthesis user's able hand. Manufacturing is realized through selective laser sintering out of durable nylon.

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