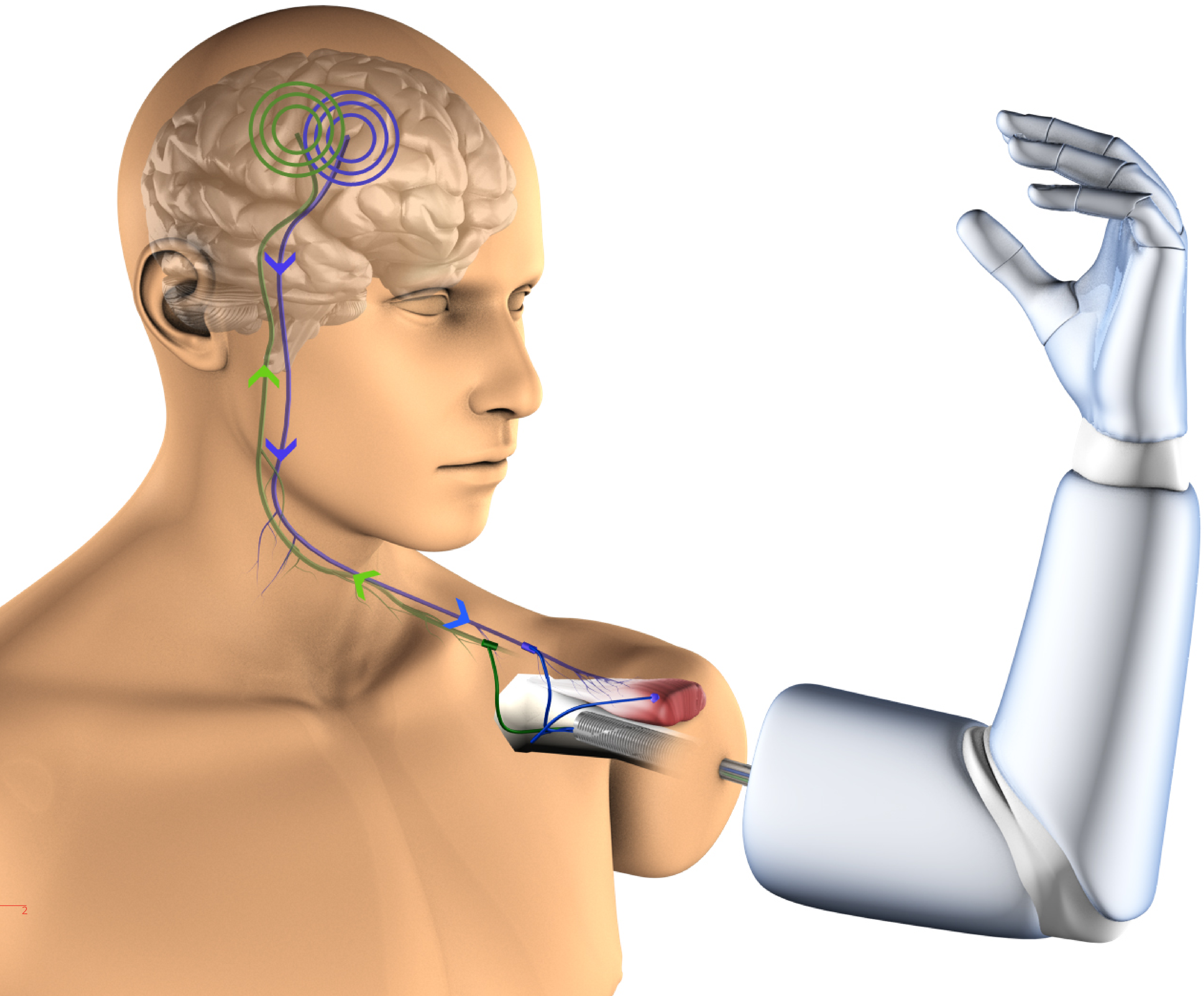
BIOMECHATRONICS AND NEUROREHABILITATION LAB

2016-2018 REPORT

Est. 2016

CHALMERS
UNIVERSITY OF TECHNOLOGY

BNL 2016-2018



BIOMECHATRONICS AND NEUROREHABILITATION LAB

TABLE OF CONTENTS

BIOMECHATRONICS AND NEUROREHABILITATION LAB

INTRODUCTION

A./Prof. Max Ortiz Catalán, Ph.D
Head of BNL

Dr. Max Ortiz Catalán presenting at the 2017 Engineering Health Day

"In this report, we present an overview of our past, present, and future projects, and highlight the accomplishments since the creation of our lab two years ago as a recognition of those who have participated in this journey" - Dr. Max Ortiz Catalán

Science and technology have the potential to improve human wellbeing when intentionally directed to do so. In 2016, as I became Assistant Professor at the department of Electrical Engineering at Chalmers University of Technology, I initiated the Biomechatronic and Neurorehabilitation Laboratory (BNL) with the purpose to research and develop technologies to restore quality of life to individuals after limb loss or motor impairments. This ambitious endeavor requires knowledge from diverse scientific and engineering disciplines. Members of our lab have different backgrounds such as electronics, physics, computer sciences, mechanics, and medicine among others. We collaborate extensively with healthcare professionals and industrial partners without whom our efforts would be futile and potentially misdirected. Moreover, we have gone beyond by including members from the social sciences, aiming to understand the impact of the technology we develop on individuals and their community. In this report, we present an overview of our past, present, and future projects, and highlight the accomplishments since the creation of our lab two years ago as a recognition of those who have participated in this journey.

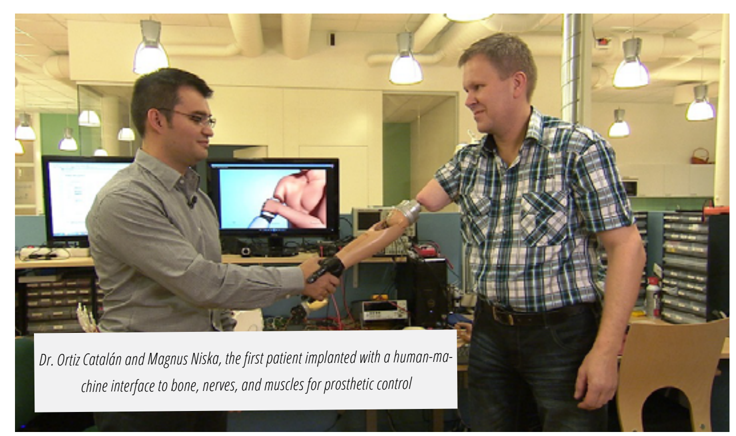
BNL is part of the Biomedical Signals and Systems research group within the division of Signal Processing and Biomedical Engineering. Our initial focus was the rehabilitation of amputees, particularly the restoration of lost function by an artificial limb. In collaboration with Integrum AB and Sahlgrenska University Hospital, in particular Prof. Rickard Brånemark, we developed the most integrated prosthetic technology directly interfacing with the user's skeletal and neuromuscular systems. This novel osseo-neuromuscular prothesis allowed for the first time the long-term use of implanted electrodes in nerves and muscles to control a prosthetic arm in daily life. We then further developed this technology to include direct nerve stimulation which resulted in the first prosthesis used in daily life that provides intuitive sensory feedback ('feeling'). Note the emphasis in "daily life", as this means that our patients are

(Left to Right) Dr. Max Ortiz Catalán, Magnus Niska and Enzo Mastinu at Cybathalon 2016 in Zurich, Switzerland

using this technology every day, all day, where it matters the most to them, and therefore improving their quality of life. Our work in different fields has amounted to a unique osseo-neuroprothetic system that is currently the only system in the world able to provide such benefits to persons with limb loss.
The clinical implementation of our technology has presented us with unique opportunities to conduct basic science research on motor control and sensory perception, as well as in neuroscience. We have continued to work on implanted and non-invasive technologies expanding our work to other amputation levels, such as below-elbow and lower limbs. Furthermore, we extended our work to what amputees consider a major problem, namely, Phantom Limb Pain (PLP). PLP can greatly hinder patients' quality of life and it is often seen as a 'mysterious' phenomenon, arguably because it's poorly understood. We developed a novel treatment named Phantom Motor Execution (PME) in which we use machine learning to decode the movement of the phantom limb while projecting it to augmented and virtual reality environments. This approach has shown improvement in patients for whom other treatments have failed, and it is currently used worldwide (BNL Technologies around the World). We are currently leading the largest international clinical trial ever conducted on PLP, as well as investigating the underlying mechanism of the condition itself by testing hypotheses on its treatment and origin that were developed in our group.

BNL team at EMBC Honolulu, Hawaii 2018

"I'm optimistic about the years to come and our capability to continue carrying on our mission 'to produce high quality and scientifically sound research and developments beneficial for humankind', towards our lab's ultimate aim to 'eliminate disability via science and technology' ". - Dr Max Ortiz Catalán



Dr. Ortiz Catalán and Magnus Niska, the first patient implanted with a human-machine interface to bone, nerves, and muscles for prosthetic control

By looking back at the journey traveled so far, I can only be thankful for the commitment and dedication of my students and collaborators in creating something beyond ourselves that has a positive impact on the life of others. I'm optimistic about the years to come and our capability to continue carrying on our mission "to produce high quality and scientifically sound research and developments beneficial for humankind", towards our lab's ultimate aim "to eliminate disability via science and technology". I hope you enjoy this report written in a popular science format, which we have found inspirational as well as informative.

Sincerely,

Max Ortiz Catalán

BNL
AT A GLANCE

From 2016-2018

ACTIVITY OF BIOMECHATRONICS AND REHABILITATION LAB

At BNL we have and continue to collaborate with leading engineering and medical institutions across the globe (Collaborators), and equally important, we cooperate closely with industrial partners such as Integrum AB, the company that pioneered osseointegrated implants for limb prostheses, as well as the two largest prosthetic companies in the world, namely, Ottobock and Össur. Our work currently spams across disciplines to integrate novel surgical and rehabilitation approaches with cutting edge medical devices, to produce clinically viable and scientifically sound biomechatronics and neurorehabilitation technologies (Project Overview).

"We strive for high quality research and take pride in the fact that not only our Ph.D. students produce scientific publications, but also seven of our M.Sc. students published their thesis results in peer-reviewed scientific journals, and five in peer-reviewed conference proceedings (full papers)"

Students are attracted to our lab not only for the possibility to help others, but also for the scientific and engineering challenges that developing new technologies represents. Students from other universities in Sweden and abroad have sought projects in our lab. In addition to our own postgraduate students, we have hosted Ph.D. and M.Sc. students from Austria, France, Germany, Switzerland, Italy, United Kingdom, and the United States of America. We strive for high quality research and take pride in the fact that not only our Ph.D. students produce scientific publications, but also seven of our M.Sc. students published their thesis results in peer-reviewed scientific journals, and five in peer-reviewed conference proceedings (full papers). In the past two years, our team has produced 17 peer-reviewed full articles for a cumulative impact factor of 89.5 (Scientific Output).

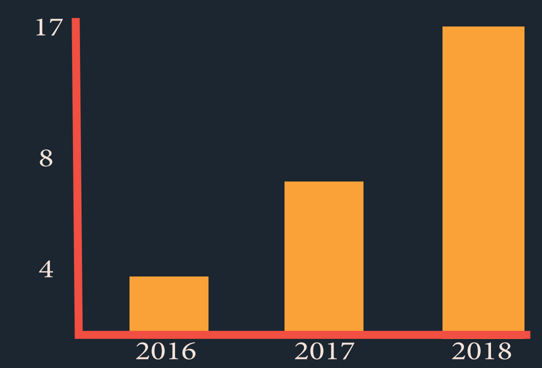
We have been honored by several prizes and awards in the past two years (Awards and Scholarships), and our work has received considerable media attention worldwide by the printed press, radio, and television (In the Media). We owe much of our ability to conduct our research to the financial support of foundations and governmental research agencies, to whom we are profoundly thankful for believing in our ideas and the quality in which they are executed. We acknowledge the support by the foundations Stiftelse Promobilia, IngaBritt och Arne Lundbergs Forskningsstiftelse, and Swedish Foundations for Strategic Research (SSF), as well as governmental agencies such as the Swedish Innovation Agency (VINNOVA), the Swedish Research Council (Vetenskapsrådet), and the European Commission. Their support has allowed us to continue and expand our work to benefit other patient populations (Funding Agencies).

SCIENTIFIC OUTPUT (2016-2018)

89.54
2 year Cumulative Impact Factor

17
Peer Reviewed Publications

CUMULATIVE PUBLICATION OUTPUT



4 PhD Students **4** Visiting PhD Scholars **20** Masters Thesis Students

22 Invited Talks
15 Invited Lectures

€1.7 M in Grants

8 Awards/ Prizes

23 Research Collaborators

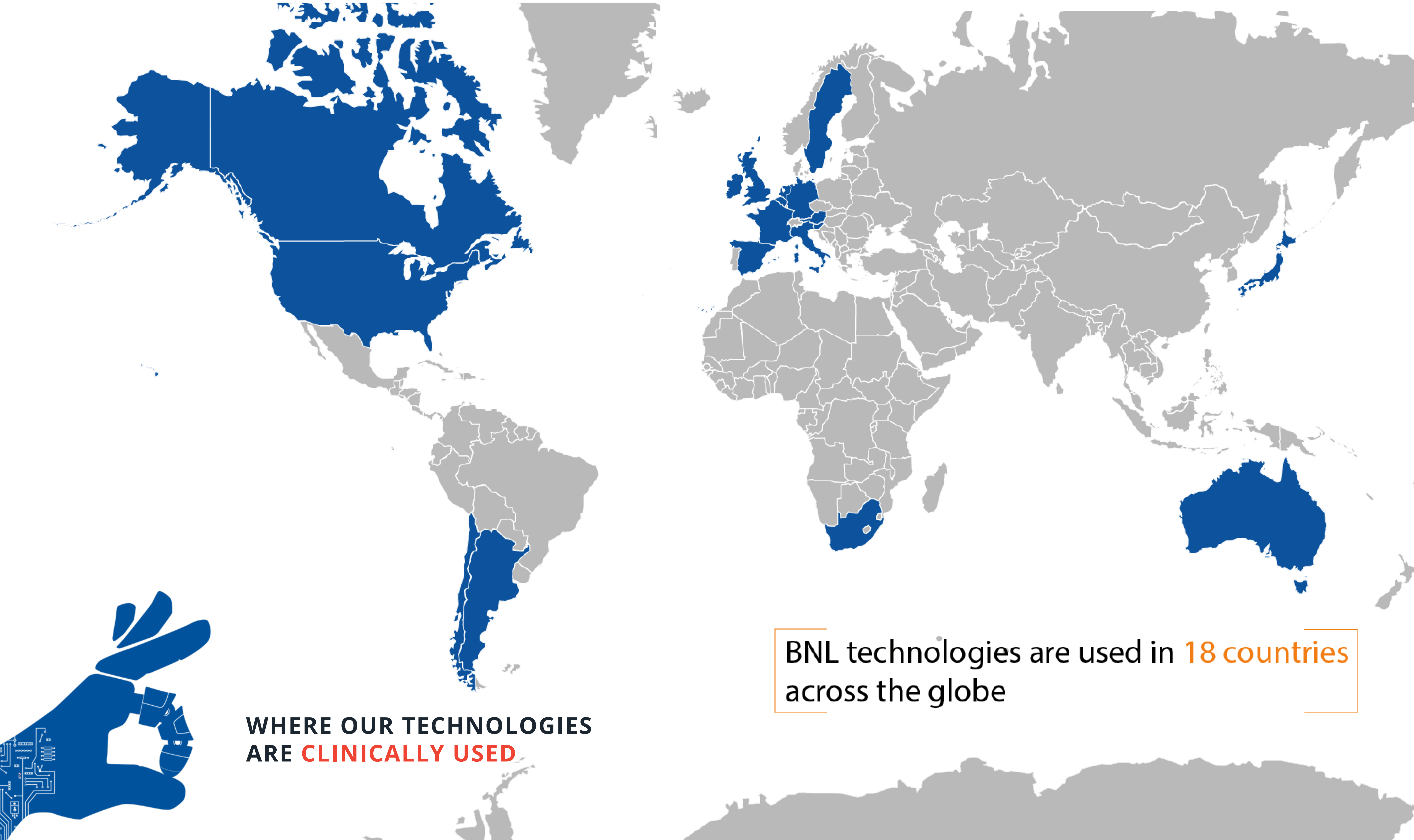
NOTABLE PUBLICATIONS

THE LANCET

Ortiz-Catalan M., Guðmundsdóttir R.A., Kristoffersen M.B., Zepeda-Echavarria A., Caine- Win terberger K., Kulbacka-Ortiz K., Widehammar C., Eriksson K., Stockselius A., Ragnš C., Pihlar Z., Burger H., and Hermansson L., Phantom motor execution facilitated by machine learning and augmented reality as treatment for phantom limb pain: a single group, clinical trial in pa tients with chronic intractable phantom limb pain, The Lancet, 2016, Vol. 388: 2885-2894.

nature bme

Ortiz-Catalan M., Deciphering neural drive, Nature Biomedical Engineering, 2017, 1, 0034.



BNL technologies are used in 18 countries across the globe

WHERE OUR TECHNOLOGIES ARE CLINICALLY USED

WHERE WE ARE LOCATED

BNL is located in beautiful Gothenburg, Sweden, at the Chalmers Campus in Johanneberg near the city center.

Gothenburg, a city of half a million people, offers a great workplace location with easy access to the archipelago, forests and lakes. We are at the geographical capital of Scandinavia with Copenhagen, Oslo and Stockholm all within a 3 hour train ride.

Our location allows us to partner with surrounding universities and hospitals where patients have come from different countries seeking to participate in the clinical investigations of our innovative technologies. We have had the honor of hosting guest lecturers from universities in Europe, the United States of America, and Japan. We have also hosted a variety of curious minds, from bachelor to graduate students.

BNL
IN THE MEDIA

MEDIA FEATURES

BBC News wrote an article about our work on the treatment of Phantom Limb Pain on their front page of Health News

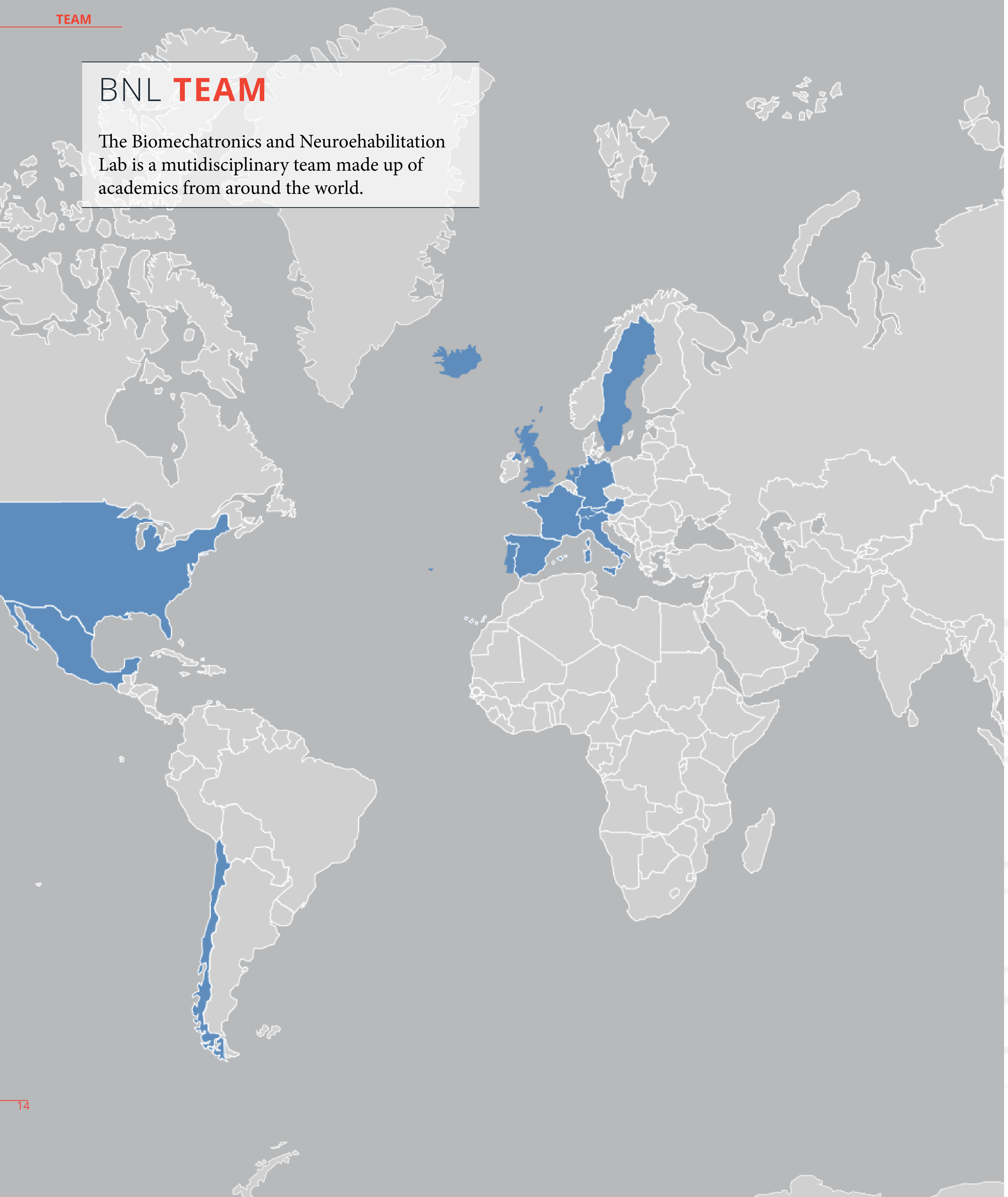
Al Jazeera filmed a feature about our work in which Dr. Joff Lacey travels to Sweden to learn about our technology described as a a pioneering union between man and machine.

SVT Vetenskapens Värld - the premier science program in Sweden - produced two documentaries on our unique prosthetic technology in which patients are using it in their daily life.

Lab Founder Dr. Ortiz Catalán, and first patient Magnus Niska, were interviewed at ***The Naked Scientist*** Podcast episode titled "Brain controlled prosthetic arm" to discuss our work with implantable technologies.

MEDIA ATTENTION AFTER PUBLICATION

Over 500 articles have been published on our work on prosthetics and Phantom Limb Pain. Printed and online articles, in over a dozen languages, as well as radio and television programs, have informed audiences about the pioneering work conducted at BNL with our collaborators.



BNL **TEAM**

The Biomechatronics and Neuroehabilitation Lab is a mutidisciplinary team made up of academics from around the world.

MAX ORTIZ CATALÁN

A./ Professor, Head of BNL

Dr. Max Ortiz Catalán, PhD, is with the Biomedical Signals and Systems research group within the Department of Electrical Engineering. He founded and heads the Biomechatronics and Neurorehabilitation Laboratory (@ChalmersBNL), and works in close collaboration Sahlgrenska University Hospital and Integrum AB, both in Gothenburg, Sweden.

ENZO MASTINU

PhD Candidate

Enzo is an Industrial PhD student at BNL, Chalmers University of Technology in collaboration with Integrum AB. He has an electronic engineering background and his research focuses on embedded systems for electromyographic signal acquisition, pattern recognition, osseointegrated implants (e-OPRA), and control of robotic prostheses.

ALEXANDER THESLEFF

PhD Student

Alexander is an Industrial PhD student at BNL, Chalmers University of Technology in collaboration with Integrum AB. His research is focused on improving prosthetic function for lower limb amputees. In particular he seeks to develop an osseointegrated implant which enables control of powered prosthetic legs by control signals obtained via implanted electrodes on remaining muscles and nerves in the residual limb.

EVA LENDARO

PhD Student

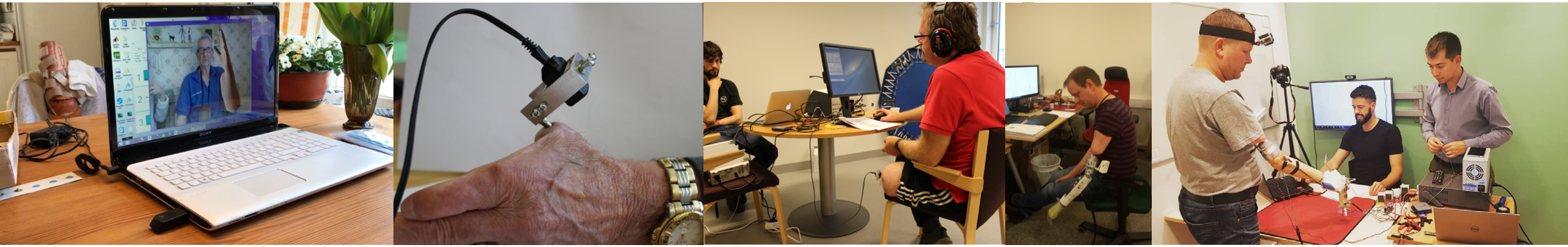
Eva 's PhD research is within neuromuscular rehabilitation for chronic pain and functional motor disability. In particular, the focus of her PhD is to solve the challenges connected with the application of the novel technologies developed at BNL to the treatment of Phantom Limb Pain. The long term goal of her project is to investigate the underlying neural mechanisms of Phantom Limb Pain which are not yet completely understood.

ADAM NABER

PhD Student

Adam Naber is a PhD student at BNL, Chalmers University of Technology. His PhD is focused on integrating brain and muscle computer interfaces with shared control and biofeedback systems for rehabilitation and enhanced accessibility. Shared control systems allow devices to make intelligent decisions based on the environment, and biofeedback is important for exploiting neuroplasticity in rehabilitation.

VISITING RESEARCHERS
PhD STUDENTS



Photos above

Visiting researcher projects and experiments

ALEXANDRA MIDDLETON

Visiting PhD Student, Medical Anthropology

Alexandra is a medical anthropologist and PhD student at Princeton working at the intersection of neuroscience, sensory ethnography, disability studies, embodiment, feminist studies of science, experimentality, and visual anthropology. She is currently conducting her dissertation fieldwork with BNL, examining these themes as they relate to the development of brain-machine-interface prosthetic technologies and the use of phantom motor execution to treat phantom limb pain (PLP). Alexandra is interested in questions of subjectivity, patienthood, care, pain, iterativity, the moral economy of hope in experimental science, and how spaces outside of the lab and clinic (i.e. the home) become sites of science-in-the-making.

FRANCESCO CLEMENTE

Visiting PhD Student, The BioRobotics Institute

Francesco was a visiting PhD student at BNL. His work focused on the design, development and testing of wearable devices for restoring sensory feedback to upper limb amputees wearing a prosthetic hand. He is currently an Assistant Professor at the BioRobotics Institute at Scuola Superiore Sant'Anna researching novel strategies for movement prediction based in machine learning and involved in national and European research projects, such as MYKI and DeTOP.

LEONARD FREDRIK ENGELS

Visiting PhD Student, The Biorobotics Institute

Leonard is a PhD student at the Artificial Hands Area in the Biorobotics Institute and holds a B.Sc. and M.Sc in Neuroscience. His research activities focus on combining insights from Neuroscience and the possibilities of current technologies to provide relevant sensory feedback to users of hand prostheses. He has conducted part of his research in partnership with BNL within the DeTOP project.

MANELLE MERAD

Visiting PhD Student , Institute of Intelligent Systems and Robotics

Manelle's research focused on the control of upper limb prosthetics, and more specifically on an intuitive control strategy of the elbow joint. At BNL she investigated the outcomes of an automatic control mode whereby the prosthetic elbow motion is estimated based on a model of natural shoulder/elbow coordinations and IMU-based shoulder measurements.

MASTER THESIS
& VISITING STUDENTS

Published full length paper in a Peer Reviewed Journal or Conference Proceedings

Chalmers Masters Students

SIMON NILSSON
Complex Adaptive Systems
Master Thesis:
Collective Dynamics in a Complex Environment

NICLAS NILSON
Biomedical Engineering
Master Thesis:
Electromyography Analysis by Classification Estimation

RITA AMADO LAEZZA
Biomedical Engineering
Master Thesis:
Deep neural networks for myoelectric pattern recognition
- An implementation for multifunctional control

CLARA GÜNTER
Biomedical Engineering
Master Thesis:
Direct stimulation of peripheral nerves to provide sensory feedback

SHANNON BROWN
Interaction Design
Master Thesis:
Development of Phantom Limb Pain Therapy System for At- Home Use

HÖGNA HRINGSDÓTTIR
Biomedical Engineering
Master Thesis:
Instrumented safety device for osseointegrated transfemoral prostheses

HANS EMIL ATLASON
Biomedical Engineering
Master Thesis:
Inertial sensors for improving electromyographic classification of hand-gestures

JOEL CEDRIC LENGELING
Software Engineering
Master Thesis:
Phantom limb visualization in first-person perspective using a head-mounted display to treat Phantom Limb Pain (PLP)

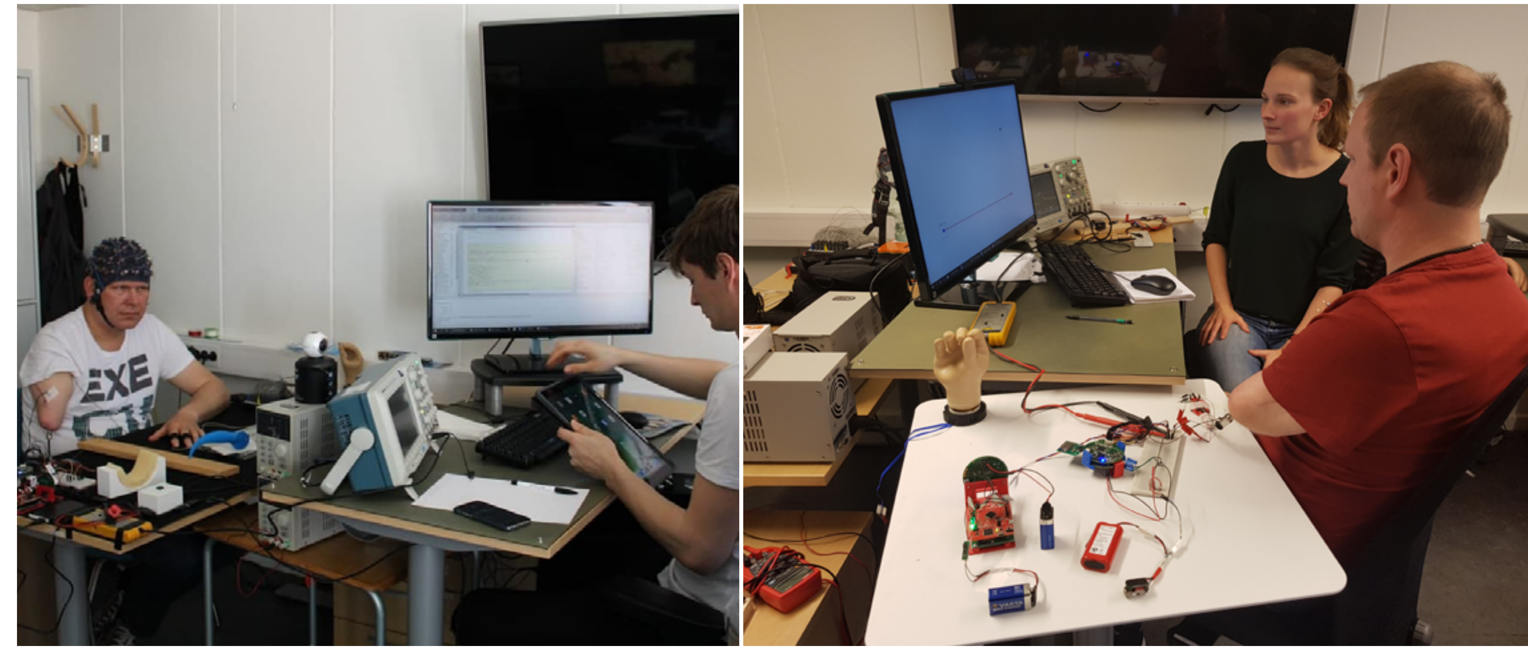
MARTIN HOLDER
Embedded System Design
Master Thesis:
Novel strategies for movement prediction based in machine learning

JASMINE BENTLER
Applied Physics
Master Thesis:
Automated testing system for an artificial limb controller and neurostimulator

ALEJANDRA ZEPEDA
Embedded System Design
Master Thesis:
Embedded load monitoring safety device for osseointegrated lower-limb amputees

EVA LENDARO
Biomedical Engineering
Master Thesis:
Promotion of motor execution for the treatment of PLP in lower limb amputations

ADAM NABER
Biomedical Engineering
Master Thesis:
Stationary Wavelet Processing and Data Imputing in Myoelectric Pattern Recognition on an Embedded System



Photos above
Masters students Jan Zbiden (photo left) and Clara Gunter (photo right) carrying out project experiments with Patients at the BNL Lab

Visiting Masters Students

University of Glasgow
REUBEN DOCEA
Biomedical Engineering
Master Thesis:
Evaluation of Muscle Activity Onset Detection Methods and Predicting Online Myoelectric Pattern Recognition Performance with Classification Complexity Estimation Algorithms

FH University of Applied Sciences TECHNIKUM WIEN
ANDREAS EILER
Mechatronics/Robotics
Master Thesis:
Improvement of simultaneous and proportional control by the evaluation of the shift in the pattern recognition's feature space using an adapted form of Fitts' Law

EPFL ÉCOLE POLYTECHNIQUE
JEREMY PATTON
Neurosciene
Master Thesis:
Mapping sensorimotor brain activity related to finger movements using high-density EEG: a feasibility study on higher resolution

IRENE BONI
Mechanical Engineering
Master Thesis:
Forearm Rotation in Trans-radial Osseointegrated Prostheses

ETH zürich
JAN ZBIDEN
Mechanical Engineering
Master Thesis:
Ownership of Prosthetic Limbs: A Study on Embodiment using Direct Neurostimulation

Universität Stuttgart
JULIAN MAIER
Medical Engineering
Master Thesis:
Wavelet Transform-based Algorithms for signal de-noising and artifact removal to improve the prediction of motor volition

Photos above

Masters Students presenting their thesis at BNL

SOPHIE LUDVIGSSON
Mechanical Engineering
Master Thesis:
Development of a Standard for Structural Testing of Implants in Transfemoral Osseointegrated Prostheses with Emilia Öhr

EMILIA ÖHR
Mechanical Engineering
Master Thesis:
Development of a Standard for Structural Testing of Implants in Transfemoral Osseointegrated Prostheses with Sophie Ludvigsson

ROBIN ANDERSSON
Robotics Engineering
Master Thesis:
Mobile platform interface for controlling and monitoring artificial limbs

SIGRÚN VÍKINGSDÓTTIR
Industrial Design
Master Thesis:
Development and design of a rehabilitation tool for phantom limb pain patients.

JOHAN AHLBERG
Medical Engineering
Master Thesis:
Real life analysis of myoelectric pattern recognition using continuous monitoring

KEVIN BREGLER
Biomedical Engineering
Master Thesis:
Instrumented safety device for trans-femoral osseointegrated patients

JASON MILENAAR
Biomedical Engineering
Master Thesis:
Enabling natural forearm rotation in transradial amputees using osseointegrated limb prostheses

EEFJE VAN DER KAADEN
Integrated Product Design
Master Thesis:
e-AD: enhanced attachment device: A new attachment for trans-humeral amputees between a myoelectric prosthesis and a bone anchored implant system

Fellowships and Visiting Students

SHANNON BROWN
Biomedical Engineering
Fellowship Project:
Intarsia-Sensorized Band and Textrodes for the Acquisition of Myoelectric Signals

JAKE GUSMAN
Biomedical Engineering
Fellowship Project:
Evaluating Fitts Law Performance in Myoelectric Controls Research

STEFANO PIRASTU
Biomedical Engineering
Internship Project:
Objects with different compliance for closed-loop prosthetic control experiments

MARIO MURGIA
Mechanical Engineering
Internship Project:
Evaluating cross-jointed implanted leads

LORENZA SICILIANI
Bionics Engineering
Internship Project:
Automated system for monitoring TMR development

DAVIDE BAGHERI
Biomedical Engineering
Internship Project:
BioPatRec and Azzurra Hand integration

ELENA VICARI
Biomedical Engineering
Internship Project:
Artificial sensors for non-human perception modalities

FRANCESCO IORI
Biomedical Engineering
Internship Project:
Integration of Swedish and Italian artificial joints.

FROUKJE PEETERS WEEM
Biomedical Engineering

Internship Project:
Design of a safety release mechanism for upper limb osseointegrated prostheses

SONJA GROTHUES
Bionics Engineering

IDEA Leauge Student Project:
Development of a fixture for control pressure on surface electromyography

HELENA MONTOLIU
Biomedical Engineering

Internship Project:
Myoelectric Pattern Recognition Data Analysis

MARIA JOSÉ MUÑOZ
Physical Therapist

Internship Project:
Implementation of Phantom motor execution as treatment for Phantom Limb Pain

Honorary Members

JUREK LAMKIEWICZ
Micromachining and Manufacturing

JASON MILLENAAR
Industrial Design

FREDRIK EKÅSEN
Electronics

SUPPORTING FACULTY

Leadership at the Biomedical Signals and Systems Research Group

SABINE REINFELDT
Associate Professor, Electrical Engineering

BO HÅKANSSON
Full Professor, Electrical Engineering

Administrative Supporting Staff

Despite not being exclusively dedicated to our laboratory, without the support of the following administrative staff at the Department of Electrical Engineering our research would not be possible:

ANN-CHRISTINE LINDBOM
Administrator

MARIA ODÉUS FORSBERG
Financial Officer

MADELEINE PERSSON
Administrator

AGNETA KINNANDER
Administrator

YVONNE JONSSON
Communications Officer

Photo Right

Top: BNL Lab Portrait Spring 2016

Middle: BNL Lab Portrait Spring 2017

Bottom: BNL Lab Portrait Fall 2017

Photo Above

BNL Lab Portrait December 2018

OUTSIDE OF THE LAB

When not researching, BNL members enjoy socializing through a range of activities from dining in town to gathering together in the cabin owned by Chalmers University of Technology for some team bonding around a cold lake and a warm fire.

BNL
AWARDS AND SCHOLARSHIPS

14TH ANNUAL DELSYS PRIZE FOR INNOVATION IN ELECTROMYOGRAPHY

Dr. Ortiz Catalán's winning proposal, titled "Myoelectric pattern recognition and augmented reality for the treatment of Phantom Limb Pain", was selected from a field of 134 entries from 29 countries. The entries represented a remarkably broad range of interests in diverse areas as Biomechanics, Exercise Physiology, Signal Processing, Facial EMG, Robotics, Rehabilitation, and various other areas.

2018 DR. PER UDDÉN'S STIPENDIUM

The Promobilia Foundation was founded in 1965 by Dr Per Uddén to promote the development of technical aids so that disabled persons could benefit of a more active life. This scholarship was instituted to honor Dr Per Uddén's memory, and was awarded to Dr. Ortiz Catalán for his work on prosthetics and phantom limb pain.

2016 EFIC-GRÜNENTHAL GRANT (E-G-G)

The EFIC-GRÜNENTHAL Grant (E-G-G) supports "young scientists in carrying out innovative and exploratory clinical pain research projects". The Scientific Research Committee of the European Pain Federation (EFIC) judged Dr. Ortiz Catalán's project proposal to be one of the 6 best of 70 research projects in competition.

2017 SER PRIZE BY THE SWEDISH SOCIETY OF ELECTRICALAND COMPUTER ENGINEERS

Awarded by SER to highlight the important contributions of the engineers to a smart and sustainable social development. Dr. Ortiz Catalán was awarded the 2017 SER prize for his work on prosthetics.

2018 SWEDISH EMBEDDED AWARD

Members of BNL and Integrum AB recieved the 2018 Swedish Embedded Award for their work on the development of an artificial limb controller. The jury dedicated the following poem to the team:

"With Artificial Limbs Controller
The difference is now much smaller
Once a dream is now for real
A new hand that can touch and feel"

ENGINEERING IN MEDICINE BIOLOGY SOCIETY STUDENT PAPER FINALIST

PhD candidate Enzo Mastinu was a finalist in the Student Paper Competition at EMBC 2018 in Honolulu, Hawaii. EMBC is the largest conference on Biomedical Engineering, and it is arranged by the IEEE Engineering in Medicine & Biology Society.

E2 EXCELLENT MASTER'S THESIS AWARD

The Department of Electrical Engineering at Chalmers annually awards excellent Master's theses . Eva Lendaro was among the 2017 awardees for her thesis entitled "Prediction of Motor Volition in the Lower Limb: Towards a Treatment for Phantom Limb Pain" within the Master's Programme in Biomedical Engineering. Here's a picture with Ants Silberberg, director of the Master programme, taken during the department's Christmas dinner.

BRIAN AND JOYCE BALCHFORD AWARD FOR INNOVATION

Dr. Ortiz Catalán and collaborators Prof. Brånemark, Prof. Håkansson, Dr. Berlin were awarded the Brian and Joyce Blatchford Award for Innovation at the ISPO conference in 2017.

Surgical and engineering team after the completion of a successful twelve hour surgery of the osseo-neuromuscular implant system.

Research and development team in 2016 at Integrum AB

Surgical and engineering team after the completion of a successful surgery of the osseo-neuromuscular implant system.

Experimental session with collaborators from Lund University and Integrum AB.

COLLABORATORS

BNL collaborates with academic, medical, and industrial professionals around the globe.

INDUSTRIAL

MEDICAL AND ACADEMIC

Swedish Collaborators

CHALMERS UNIVERSITY OF TECHNOLOGY

Prof. Torbjörn Lundh, PhD, Mathematical Sciences

Prof. Yiannis Karayiannidis, PhD, Mechatronics, Electrical Engineering Dept.

SAHLGRENSKA UNIVERSITY HOSPITAL / GOTHENBURG UNIVERSITY

Prof. Rickard Brånemark, MD, PhD, Orthopedics Dept.

Dr. Paolo Sassu, MD, PhD, Hand Surgery Dept.

Prof. Johan Wessberg, PhD, Neurophysiology Dept.

Dr. Roy Tranberg, PhD, Orthopedics Dept.

Dr. Roland Zügner, PhD ,Orthopedics Dept.

Prof. Anders Palmquist, PhD, Biomaterials Dept.

Dr. Mariama Dione, PhD, Physiology Dept.

Dr. Malin Björnsdotter, PhD, Phychiatry and Neurochemistry Dept.

Prof. Katharina Stilbrant Sunnerhagen,MD, PhD, Clinical Neuroscience Dept.

Dr. Margit Alt Murphy, PhD, PT, Clinical Neuroscience Dept.

Linnéa Andersson, Radiation Physics Dept.

CENTRE FOR ADVANCED RECONSTRUCTION OF EXTREMITIES (C.A.R.E) AT SALHGRENSKA

Dr. Carina Reinholdt, PhD, MD

Katarzyna Kulbacka-Ortiz

Prof. Kerstin Hagberg, PhD, PT

Prof. Lina Bunketorp Käll, PhD, PT

Dr. Johanna Wangdell, PhD, OT

Charlotte Schürer von Waldheim

PROSTHETIC AND ORTHOTICS DEPARTMENT

Peter Sommar, CPO

Kristina Wallin, CPO

Emma Johansson, CPO

Ingrid Rignér, PT

Emilia Diamantidis, PT

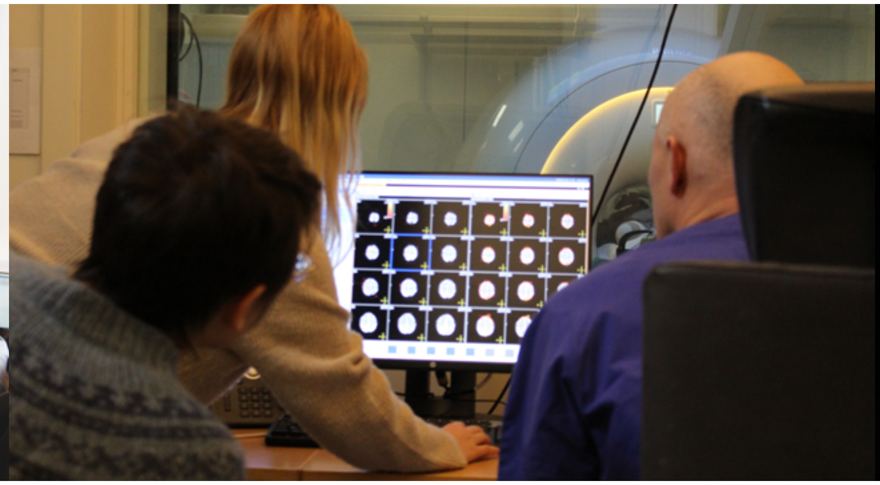
ÖREBRO UNIVERSITY

Prof. Liselotte Hermansson, PhD, OT, Prosthetics and Orthotics Dept.

Dr. Cathrine Widehammar, PhD, OT, Prosthetics and Orthotics Dept.

Kajsa Lidström-Holmqvist, PhD, OT, Prosthetics and Orthotics Dept.

Collaborators from University of Borås visit BNL to test textile electrodes for sEMG aquisition



BNL, Gothenburg University and Sahlgrenska University Hospital Researchers analyze FMRI scans of a patient experiencing phantom limb pain

Kick-off meeting of the European project DeTOP

UNIVERSITY OF BORÅS
Prof. Fernando Seaone, PhD, Textile Technology Dept.
Dr. Li Guo, PhD, Textile Engineer, Textile Technology Dept.
Prof. Leif Sandsjö, PhD, Work Life and Social Welfare Dept.

MÄLARDALEN UNIVERSITY
Prof. Maria Linden, PhD, Division of Intelligent Future Technologies
Dr. Sara Abbaspour, PhD, Division of Networked and Embedded Systems

TEAM OLMED
Stewe Jönsson, CPO

BRÄCKE DIAKONI
Christina Ragnö, PT

AKTIV ORTOPEDTEKNIK
Anita Stockselius, PT
Lena Gudmundson, PT

LUND UNIVERSITY
Prof. Christian Antfolk, PhD, Biomedical Engineering Dept.
Dr. Nebojša Malesevic, PhD, Biomedical Engineering Dept.

European Collaborators

SCUOLA SUPERIORE SANT'ANNA
Prof. Christian Cipriani, PhD, The BioRobotics Institute
Prof. Marco Controzzi, PhD, The BioRobotics Institute
Prof. Francesco Clemente, PhD, The Biorobotics Insititute

NATIONAL UNIVERSITY OF IRELAND, GALWAY
Prof. Brian McGuire, PhD, Centre for Pain Research

TRINITY COLLEGE DUBLIN
Monika Pilch, PhD.c, Center for Health Policy and Management, School of Medicine

UNIVERSITY OF ESSEX
Prof. Riccardo Poli, PhD, School of Computer Science and Electronic Engineering
Dr. Luca Citi, PhD, School of Computer Science and Electronic Engineering
Dr. Ana Matran-Fernandez, PhD, School of Computer Science and Electronic Engineering

SORBONNE UNIVERSITY
Dr. Nathanaël Jarrassé, PhD, Institute of Intelligent Systems and Robotics, CNRS, INSERM
Dr. Manelle Merad, PhD, Institute of Intelligent Systems and Robotics, CNRS, INSERM

GHENT UNIVERSITY
Prof. Jean Delbeke, MD, PhD, Academic Consulant

Collaborators from Integrum AB and Prof. Brånemark at IASPT 2018 in Vienna

Dr. Ortiz Catalán Lectures at IASPT 2018 at the Medical Univeristy in Vienna

GHENT UNIVERSITY HOSPITAL

Dr. Wim Vanhove, MD, Orthopaedic Surgery and Traumatology Dept.

Dr. Sybille Geers, MD, Physical Medicine and Rehabilitation

Sonia Degarve, PT, Physical Medicine and Rehabilitation

FUNDACIÓN LESION MEDULAR

Dr. Natacha León, MD

Sara Cáceres Saavedra, PT

AUTONOMOUS UNIVERSITY OF BARCELONA

Prof. Xavier Navarro, MD, PhD, Physiology and Immunology Dept.

CENTRE SUISSE DÉLECTRONIQUE ET DE MICROTECHNIQUE CSEM

Dr. Marc Pons Solé, PhD

CATALAN INSTITUTE OF NANOSCIENCE AND NANOTECHNOLOGY (ICN2)

Prof. Jose Antonio Garrido, PhD, Advanced Electronic Materials and Devices Group

UNIVERSITY OF PADERBORN

Dr. Alexander Boschmann, PhD, Computer Engineering

MEDICAL UNIVERSITY OF VIENNA

Prof. Oskar Aszmann, PhD, Division of Plastic and Reconstructive Surgery

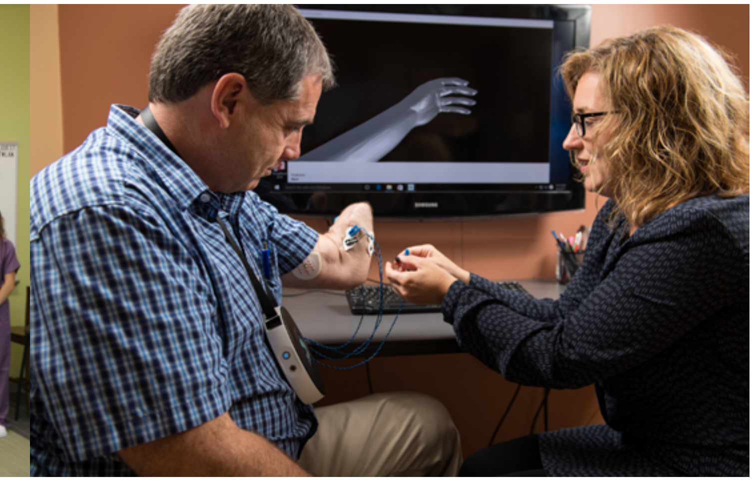
UNIVERSITY MEDICAL CENTER GRONINGEN

Prof. Corry van Der Sluis, PhD, Rehabilitation Medicine

BOĞAZIÇI ÜNIVERSITESI

Prof. Burak Güçlü, PhD, Institute of Biomedical Engineering

Collaborators at Harvard Medical School, MIT and UCSF



BNL's collaborators on international PLP clinical trial at the University of New Brunswick

North American Collaborators

NORTHWESTERN UNIVERSITY

Prof. Levi Hargrove, PhD, Dept. of Physical Medicine & Rehabilitation

SHIRLEY RYAN ABILITY LAB

Prof. Levi Hargrove, PhD, Center for Bionic Medicine

UNIVERSITY OF MICHIGAN

Prof. Cynthia Chestek, PhD, Dept. of Biomedical Engineering

Prof. Paul Cederna, MD, Dept. of Biomedical Engineering (Plastic Surgery)

HARVARD MEDICAL SCHOOL

Prof. Matthew J. Carty, PhD, MD, Surgery Dept.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Prof. Hugh Herr, PhD, Biomechatronics group at MIT Media Lab

UNIVERSITY OF NEW BRUNSWICK

Prof. Jon Sensinger, PhD, Electrical and Computer Engineering

Wendy Hill, OT, Dept. of Biomedical Engineering

UNIVERSITY OF ALBERTA

Prof. Jacqueline Hebert, MD, FRCPC, Dept. of Rehabilitation Medicine

CHAMPAIGNE KLASSEN

Dr. Keith Kassen, Rehabilitation Psychologist

Dr. Ortiz Catalán demonstrates the PLP therapy developed at BNL at Hospital del Trabajador, Chile

Elma Hofmeyer from South Africa meets with Maria José Muñoz, a visiting clinician at BNL to learn about our work on PLP

South American Collaborators

HOSPITAL DEL TRABAJADOR

Dr. Rainhold Garcia, MD, Traumatology

Dr. Jessica Castillo, Physiatrist (Physical Medicine and Rehabilitation)

UNIVERSIDAD DE BUENOS AIRES

Prof. Leila C. Milco, PT, Biomechanics

African Collaborations

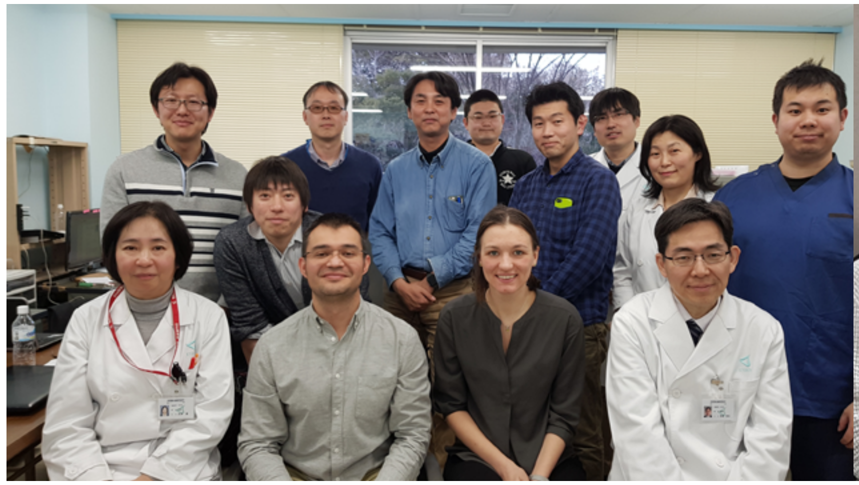
CHIN AND PARTNERS

Justin Rix, CPO

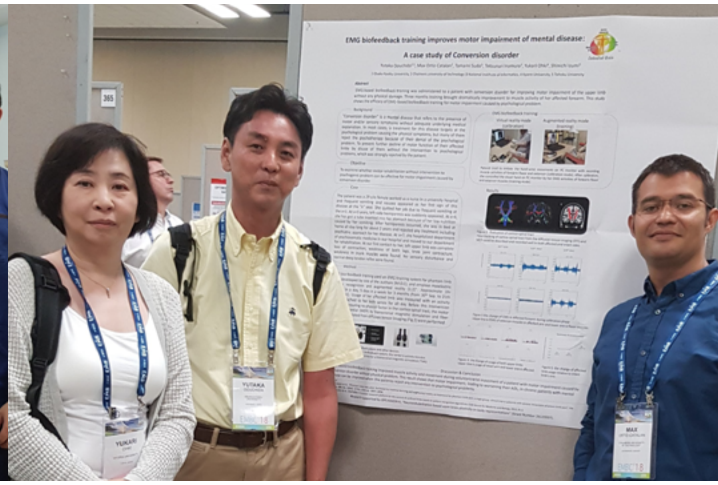
Jayson Chin, CPO

ELMA HOFMEYR

Registered Counsellor



Dr. Ortiz Catalán and Eva Lendaro visit Japanese Collaborators from Kyorin Univerisity and Tohoku University Hospital



Presentation of joint conference article between BNL and Japanese collaborators

Australian and Asian Collaborators

EPWORTH HEALTHCARE

Abby Hutchison, PT

Jemma Keeves, PT

THE ALFRED UNIVERSITY HOSPITAL

Steven Gray, Plastic, Hand & Faciomaxillary Surgery Unit Dept.

Dr. Frank Bruscino-Raiola, MD, Plastics, Hand and Faciomaxillary Surgery Dept.

SIR CHARLES GAIRDNER HOSPITAL

Beck Hefferon, PT

KYORIN UNIVERSITY

Prof. Yakari Ohki

Dr. Hiroyuki Ohtsuka

TOHOKU UNIVERSITY HOSPITAL

Dr. Yukata Oochida, MD, PhD

UNIVERSITY OF TOKYO

Prof. Wen Wen, PhD, Dept. of Precision Engineering

PUBLICATIONS

Publication	IMPACT FACTOR
Ortiz-Catalan M., Guðmundsdóttir R.A., Kristoffersen M.B., Zepeda-Echavarria A., Caine-Winterberger K., Kulbacka-Ortiz K., Widehammar C., Eriksson K., Stockselius A., Ragnö C., Pihlar Z., Burger H., and Hermansson L., Phantom motor execution facilitated by machine learning and augmented reality as treatment for phantom limb pain: a single group, clinical trial in patients with chronic intractable phantom limb pain, The Lancet, 2016, Vol. 388: 2885-2894.	53.25
Ortiz-Catalan M., Deciphering neural drive, Nature Biomedical Engineering, 2017, 1, 0034.	New
Lendaro E., Mastinu E., Håkansson B., and Ortiz-Catalan M., Real-time classification of non-weight bearing lower limb movements using EMG to facilitate phantom motor execution: engineering and case study application on phantom limb pain, Frontiers in Neurology, 2017, 8:470.	3.27
Clemente F., Håkansson B., Cipriani C., Wessberg J., Kulbacka-Ortiz K., Brånemark R., Fredén Jansson KJ., and Ortiz-Catalan M., Touch and hearing mediate osseoperception, Scientific Reports (Nature), 2017, 45363.	4.61
Mastinu E., Doguet P., Botquin Y., Håkansson B., and Ortiz-Catalan M., Embedded system for prosthetic control using implanted neuromuscular interfaces accessed via an osseointegrated implant, IEEE Transactions on Biomedical Circuits and Systems, 2017, 11 (4), 867-877.	3.50

Publication	IMPACT FACTOR
Nilsson S., Håkansson B., and Ortiz-Catalan M., Classification Complexity in Myoelectric Pattern Recognition, Journal of Neuroengineering Rehabilitation, 2017, 14:68.	3.87
Gusman J., Mastinu E., and Ortiz-Catalan M., Evaluation of Computer-Based Target Achievement Tests for Myoelectric Control, IEEE Journal of Translational Engineering in Health and Medicine, 2017, 5:1.	1.75
Thesleff A., Brånemark R., Håkansson B., and Ortiz-Catalan M., Biomechanical characterisation of bone-anchored implant systems for amputation limb prostheses: a systematic review, Annals of Biomedical Engineering, 2018, 46 (3), 377-391.	3.41
Mastinu E., Ahlberg J., Lendaro E., Håkansson B., and Ortiz-Catalan M., An alternative myoelectric pattern recognition approach for the control of hand prostheses: A case study of use in daily life by a dysmelia subject, IEEE Journal of Translational Engineering in Health and Medicine, 2018, 6 (1), 1-12.	1.75
Ortiz-Catalan M., Restoration of somatosensory perception via electrical stimulation of peripheral nerves, Journal of Clinical Neurophysiology, 2018, 129, 851-862.	1.98
Lendaro E., Hermanson L., Helena Burger H., Van der Sluis C., McGuire B., Pilch M., Bunketorp-Käll L., Kulbacka-Ortiz K., Rignér I., Stockselius A., Gudmundson L., Widehammar C., Hill W., Geers S., and Ortiz-Catalán M., Phantom Motor Execution as a treatment for Phantom Limb Pain: Protocol of an international, double-blind, randomised, controlled clinical trial, British Medical Journal Open, 2018, 8:e021039.	2.41
Ackerley R., Backlund H., Ortiz-Catalan M., Brånemark R., and Wessberg J., Case Studies in Neuroscience: Sensations elicited and discrimination ability from nerve cuff stimulation in an amputee over time, Journal of Neurophysiology, 2018, 120:291-295.	2.50

	IMPACT FACTOR
Ortiz-Catalan M., “The stochastic entanglement and phantom motor execution hypotheses: a theoretical framework for the origin and treatment of PLP”, Frontiers in Neurology, 9:748.	3.37
Boni I., Millenaar J., Controzzi M., and Ortiz-Catalan M., Restoring natural forearm rotation in transradial osseointegrated amputees, IEEE Transactions on Neural System and Rehabilitation Engineering, 26 (12), 2333-2341.	3.97
Günter C., Delbeke J., and Ortiz-Catalan M., Safety of long-term peripheral nerve stimulation: Review of the state of the art, Journal of NeuroEngineering Rehabilitation, Accepted.	3.87

CONFERENCE PUBLICATIONS (FULL PAPERS)

Our team has presented at professional conferences around the world including the Annual Conference of the IEEE *Engineering in Medicine and Biology Society* (EMBC) and the *International Conference on Pattern Recognition* (ICPR).

CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY

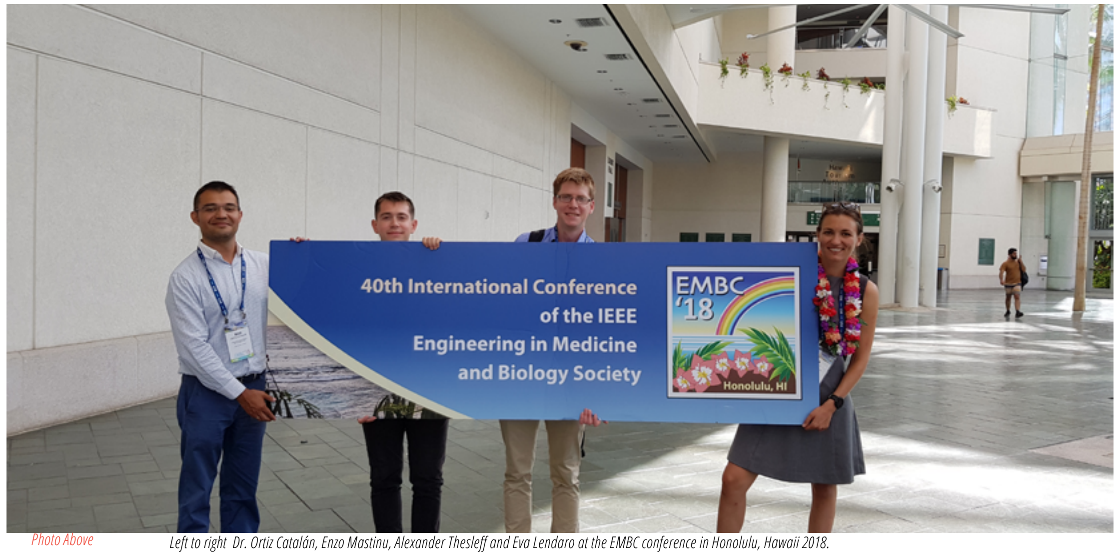


Photo Above Left to right Dr. Ortiz Catalán, Enzo Mastinu, Alexander Thesleff and Eva Lendaro at the EMBC conference in Honolulu, Hawaii 2018.

38TH ANNUAL EMBC ORLANDO, AUG. 16-20, 2016

- Classification of Non-Weight Bearing Lower Limb Movements: Towards a Potential Treatment for Phantom Limb Pain Based on Myoelectric Pattern Recognition by Eva Lendaro and Max Ortiz Catalán
- Intarsia-Sensorized Band and Textrodes for the Real-Time Acquisition of Myoelectric Signals by Shannon Brown, Max Ortiz Catalán, Fernando Seoane et. al.
- Digital Controller for Artificial Limbs Fed by Implanted Neuromuscular Interfaces via Osseointegration by Enzo Mastinu, Max Ortiz Catalán and Bo Håkansson.

40TH ANNUAL EMBC HONOLULU, AUG. 17-21, 2018

- Differential Activation of Biceps Brachii Muscle Compartments for Human-Machine Interfacing by Eva Lendaro, Simon Nilsson and Max Ortiz Catalán
- Load Exposure of Osseointegrated Implants for Transfemoral Limb Prosthesis During Running, Alexander Thesleff, Sophie Ludvigsson, Emilia Öhr, and Max Ortiz Catalán
- Myoelectric Signals and Pattern Recognition from Implanted Electrodes in Two TMR Subjects with an Osseointegrated Communication Interface by Enzo Mastinu, Rickard Brånemark, Oskar Aszmann, and Max Ortiz Catalán
- Crosstalk Reduction in Epimysial EMG Recordings from Transhumeral Amputees with Principal Component Analysis by Ana Matran-Fernandez, Enzo Mastinu, Ricardo Poli, Max Ortiz Catalán, and Luca Citi

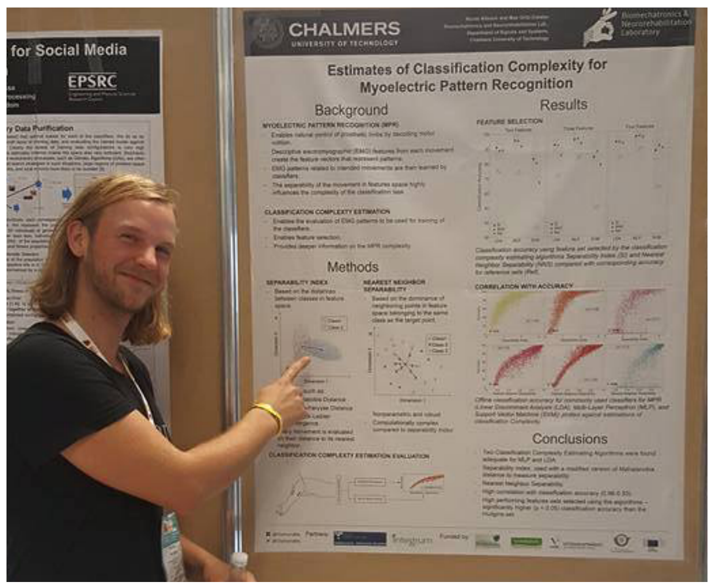


Photo Above
BNL Masters Student Nicklas Nilsson presents his work at ICPR 2016

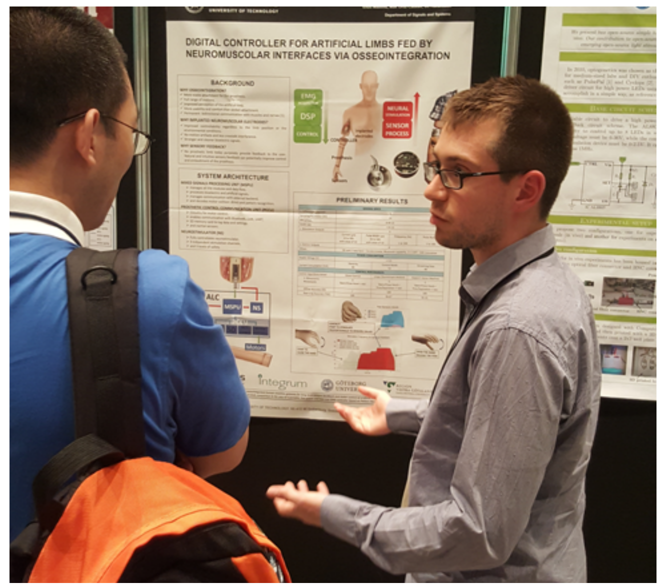


Photo Above
Enzo Mastinu presents his research at EMBC 2018

23RD INTERNATIONAL CONFERENCE ON PATTERN RECOGNITION (ICPR), CANCUN, DEC. 4-8, 2016

- Estimates of Classification Complexity for Myoelectric Pattern Recognition by Nicklas Nilsson and Max Ortiz Catalán

2ND INTERNATIONAL CONFERENCE ON SMART PORTABLE, WEARABLE, IMPLANTABLE AND DISABILITY-ORIENTED DEVICES AND SYSTEMS (SPWID), VALENCIA, MAY 22-26, 2016

- Intarsia-Sensorized Band and Textrodes for the Acquisition of Myoelectric Signals by Shannon Brown, Fernando Seoane Martínez and Max Ortiz Catalán et. al.

INVITED TALKS 2016-2018

Given by Dr. Ortiz Catalán

KEYNOTE SPEAKER

10/2019	International Society of Prosthetics and Orthotics – World Congress, Kobe, Japan
05/2018	European Congress of Rehabilitation Medicine, Vilnius, Lithuania.
10/2017	Congress of the French Society of Physical and Rehabilitation Medicine, Nancy, France
05/2017	Osseo 2017, Nijmegen, Netherlands.
04/2017	Annual Conference of the Swedish Technical Audiology Society, Gothenburg, Sweden
03/2017	Int. Conf. Advances in Orthopaedic Osseointegration, San Diego, USA.
11/2016	Orto Medical Care, Madrid, Spain
06/2016	User Body Experience and HMI Assistive Robotics, Darmstadt, Germany.
05/2016	OT World, Leipzig, Germany

INVITED SPEAKER

10/2018	iMed Conference, Lisbon, Portugal
06/2018	Young Scientist Association 14th Symposium, Medical University of Vienna
06/2018	IV Jornadas de Ortoprotesia, Escola Superior de Tecnologia da Saúde de Lisboa
04/2018	Elektronikindustriföreningen i Göteborg (EIG), Gothenburg, Sweden
01/2018	ISPO UK Osseointegration Workshop, London, England
11/2017	ARMADA Talsk 2017, Stockholm, Sweden
10/2017	Svenskt Smärtforum (Swedish Pain Forum), Gothenburg, Sweden
07/2017	Rehabilitation Medicine Society of Australia and New Zealand, Canberra, Australia
04/2017	Leva & Fungera (Nordic conf. for Assistive Technology and Accessibility), Gothenburg, Sweden
03/2017	Handdagar (Swedish Society for Hand Rehabilitation), Malmö, Sweden.
02/2017	Nordiskt Tvärfackligt Forum för Dysmeli och Armamputation, Stockholm, Sweden
05/2016	Restoration of Sensory and Motor Function Symposium, Göttingen, Germany
02/2016	TEDx Mexico City, Mexico City, Mexico

Photo top

Jason Millenaarr presents his work with the DeTOP Project

Photo bottom

Symposium attendees watch presentations at the 3rd Bionic Limbs and Neurorehabilitation Symposium in 2017

SYMPOSIUMS AND WORKSHOPS ORGANIZED BY BNL

08/2018 Workshop: “Advances in Embodied-Brain Systems Science and rehabilitation” workshop at IEEE EMBC 2018, Honolulu, USA. (co-organizer)

02/2018 Symposium: “4th Bionic Limbs and Neurorehabilitation Symposium” at Chalmers University of Technology, Gothenburg, Sweden

05/2017 Symposium: “3rd Bionic Limbs and Neurorehabilitation Symposium” at Chalmers University of Technology, Gothenburg, Sweden

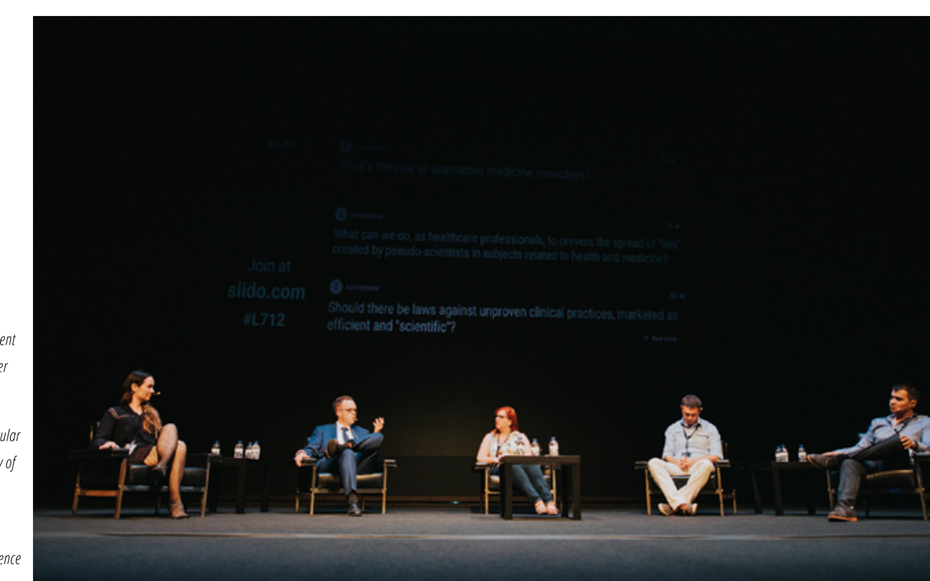
08/2016 Workshop: “Embodied-Brain Systems Science and Neurorehabilitation” at IEEE-EMBC 2016, Orlando, USA (co-organizer)

06/2016 Symposium: “2nd Bionic Limbs and Neurorehabilitation Symposium” at Chalmers University of Technology, Gothenburg, Sweden

11/2015 Symposium: “1st Bionic Limbs and Neurorehabilitation Symposium” at Chalmers University of Technology, Gothenburg, Sweden

POPULAR SCIENCE COMMUNICATION

At BNL we have had the opportunity to share our work with the wider public through fairs, expos panel discussions and public gatherings.



Photos right

1. Dr. Ortiz Catalán presenting for French President Emmanuel Macron and Swedish Prime Minister Stefan Löfven

2. Enzo Mastinu describing the osseo-neuromuscular interface and artificial limb controller to the jury of the Swedish Embedded Award

3. Dr. Ortiz Catalán participating on a panel discussion addressing the dangers of pseudo-science on medical practice at IMED 2018

PROJECT OVERVIEW
BIOMECHATRONIC LIMB PROSTHESIS

Despite decades of research and development on artificial limbs and neural interfaces, patients with missing limbs are commonly provided with fundamentally the same prosthetic solutions as those offered 50 years ago. This reality contrasts with sensationalistic media reports, as patients were not able to benefit from the sophisticated prosthetic devices featured in popular science outlets. The actual take-home prostheses given to patients did not purposely provide sensory feedback and suffered from poor functionality owing to the low-resolution and unreliable human-machine interfaces available for their attachment and control. Thanks to a synergistic collaboration between engineering, medical, and industrial partners, our extended group has now managed to move the field forward with the development of a novel osseo-neuromuscular technology that allows for stable mechanical attachment and natural control of artificial limbs.

In this context, “natural” is defined as providing control in the same way as an intact biological system. This means coordinated and simultaneous movements of different degrees of freedom (for instance, wrist rotation while closing the hand). It also implies that the input signals come from nerves or muscles that were originally meant to produce the intended movement (physiologically appropriate). Furthermore, natural control requires sensory feedback perceived as originating in the missing limb, without requiring overwhelming concentration from the user.

"Limb prostheses were initially cosmetic, then mechanic, and ultimately mechatronic. This evolution was driven by the aim to restore function. However, as opposed to autonomous mechatronic or robotic devices, limb prostheses must be commanded seamlessly (or naturally) by their users, and thus must integrate biologically. Our work centers around replacing missing limbs with biomechatronic prosthesis that are ever-more integrated into the user’s biology, thus allowing for natural control, which in turn ultimately leads to improved function. " -Dr. ORTIZ CATALÁN PhD

Photo Right
Magnus Niska participates in the Cybathlon Competition in 2016, an event in which people with physical disabilities compete against each other to complete everyday tasks using state-of-the-art assistance systems.

BIOMECHATRONIC LIMB PROSTHESIS

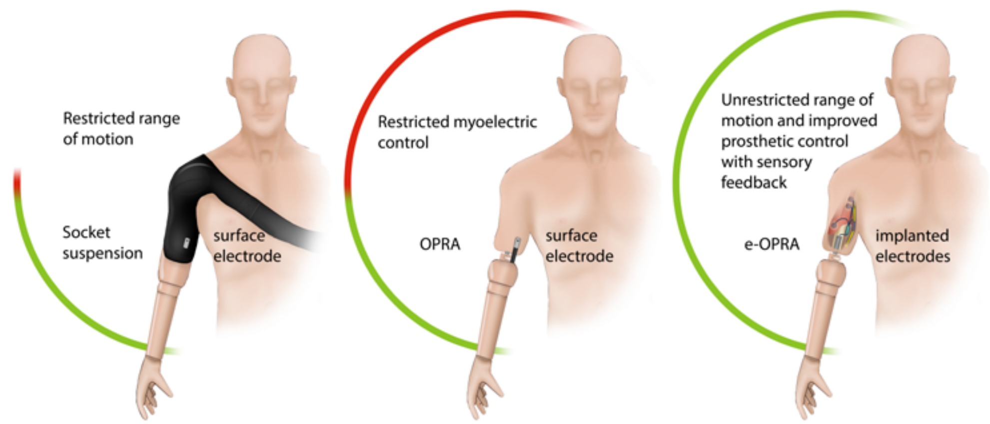


Photo above

Progression from conventional prosthetic technology using socket suspension and surface electrodes for control, to the latest osseo-neuromuscular prosthesis with direct skeletal attachment and implanted electrodes in nerves and muscles for control and sensory feedback.

Photo below

Left to right: Dr. Ortiz Catalán, Magnus Niska, and Prof. Brånemark in the fitting of the first osseo-neuromuscular prosthesis.

OSSEO-NEUROMUSCULAR INTERFACING

The use of implantable electrodes has been long thought as the solution for a more natural control of artificial limbs, as they offer access to long-term stable and physiologically appropriate sources of control, as well as the possibility to elicit appropriate sensory feedback via neurostimulation. Although these ideas have been explored since the 1960's, the lack of a long-term stable human-machine interface has prevented the utilization of even the simplest implanted electrodes in clinically viable limb prostheses.

We have overcome this problem by using osseointegration, a phenomenon discovered in Sweden in the 1950's by Prof. P.I. Brånemark, and initially used for the invention of dental implants. This concept was then developed further by Prof. Rickard Brånemark to allow for direct skeletal attachment of limb prosthesis, which has been a landmark technology on prosthetics by its own. In collaboration with Prof. Brånemark, we have now taken this mechanical human-machine interface, and enhanced it to also allow for long-term stable, safe, and reliable bidirectional communication between implanted neuromuscular electrodes and the artificial limb. The long-term stability, safety, and reliability of this osseo-neuromuscular technology makes it clinically viable, meaning that patients can be provided with a prosthesis connected to their skeleton, nerves, and muscles to be used in daily life. Currently this is the only self-contained (no additional backpacks containing power and processing equipment that the patient must carry around) neuroprosthetic system that allows for neural closed-loop control used outside research laboratories and in patients' daily activities without supervision.

Photo above

X-ray of the neuromusculoskeletal prosthesis presents the intimate interfacing between human and machine. Pure biology gradually integrated the artificial mechatronic limb.

TRANSHUMERAL (ABOVE-ELBOW) BIOMECHATRONIC PROSTHESIS

In January 2013, the first subject with transhumeral amputation was implanted with our osseo-neuromuscular technology. He has used his now biomechatronic limb prosthesis in daily life uninterruptedly since then, over five years ago. We then developed an embedded system that also allowed for direct nerve stimulation, thus making him the first subject to control and feel with his prosthesis using implanted neural interfaces in the world. Four more subjects have been implanted since then in an on-going clinical trial, where we are now combining novel nerve transfer surgical techniques to increase the number of intuitively control movements.

TRANSRADIAL (BELOW-ELBOW) BIOMECHATRONIC PROSTHESIS

The osseo-neuromuscular technology for above-elbow amputees could not be directly transferred to below-elbow amputations owing to clear anatomical differences. That is, the forearm is made of two smaller bones rather than a single larger one as in the upper arm. This posed several challenges on the development of the implant technology. On the other hand, it also presents an opportunity to achieve a more dexterous control of an artificial replacement because many more muscles are available to extract neural commands in below-elbow amputations.

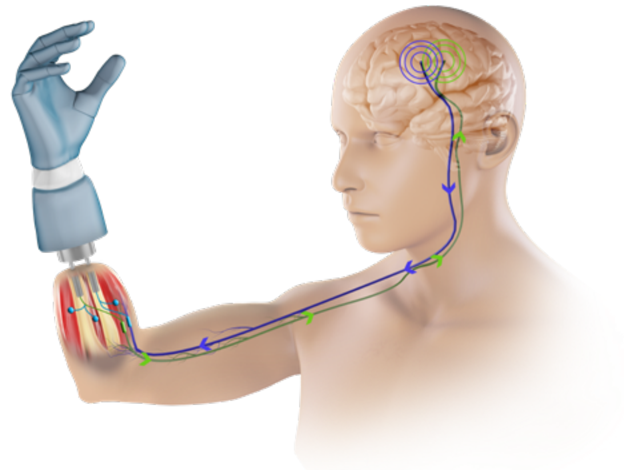


Photo above

Biomechatronic prosthesis for below-elbow amputation. Osseo-neuromuscular interfaces are placed in each of the remaining forearm bones.

In collaboration with Integrum AB, we nevertheless managed to solve the challenge and the first patient with such system was implanted in December 2018 as part of a larger European project DeTOP. The DeTOP project is coordinated by the Scuola Superiore Sant'Anna, and also includes Prensilia, the University of Gothenburg, Lund University, University of Essex, the Swiss Center for Electronics and Microtechnology, INAIL Prosthetic Center, Università Campus Bio-Medico di Roma, and the Instituto Ortopedico Rizzoli.

Photo above

Patient with below-elbow amputation with an artificial joint that allows for natural wrist rotation.

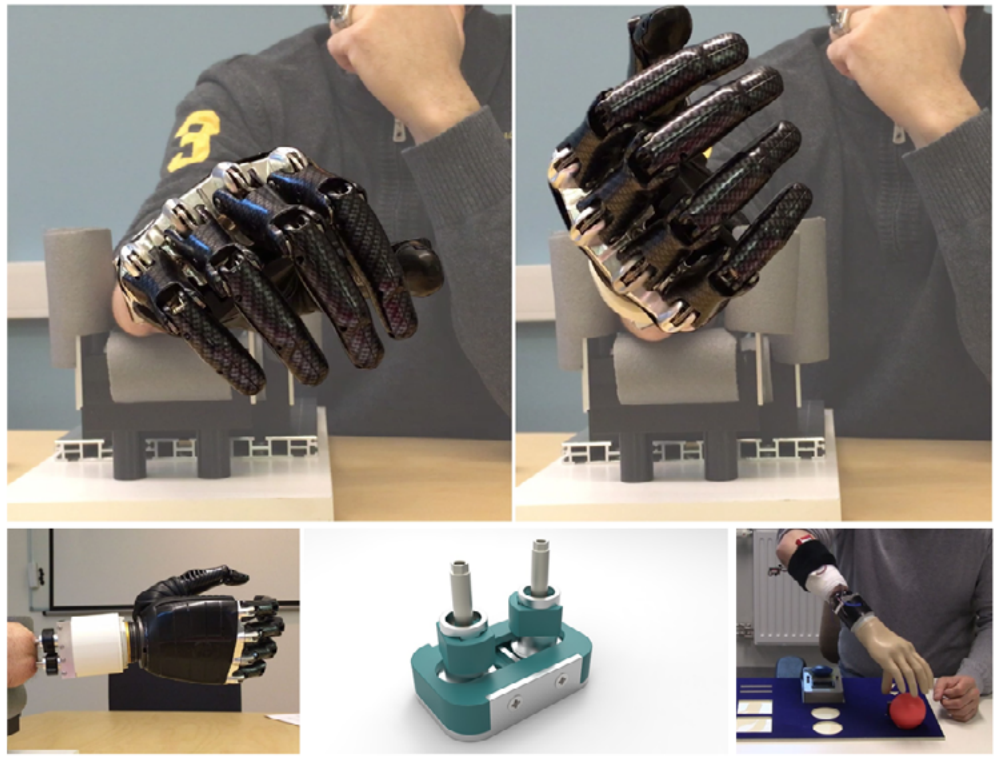


Photo above
Artificial joint to enable wrist rotation for patients with below-elbow amputations.

ARTIFICIAL JOINT TO ENABLE WRIST ROTATION (A.K.A. "EL ROTADOR")

Below-elbow amputees are often still able to perform natural forearm rotation. Having this natural motion enabled when using a prosthesis is beneficial in activities of daily living and prevents compensatory movements, which in turn reduces consequential health issues over time. A conventional socket prosthesis locks any remaining forearm rotation, as opposed to using osseointegrated implants that preserve this motion. However, although the forearm bones are free to move when using osseointegrated implants, such implants are locked in place for safety and lack an artificial joint that could account for the complex resulting motions of the bones during wrist rotation. We addressed this problem and developed an artificial joint between the osseointegrated implants and the prosthetic hand which preserves natural forearm rotation in a safe and comfortable way.

We have performed a number of experiments aiming to understand the mobility of the implants required to preserve natural forearm rotation, how to load the implants safely and comfortably, and how the ability to perform this movement improves the performance of everyday tasks.

We found that with limited individual movement of the implants we can preserve forearm rotation and distribute loads equally between the two implants without inducing unpleasant feelings for the patient. Furthermore, daily task performance improved considerably with natural forearm rotation.

This artificial joint that allows wrist rotation, a.k.a. "el Rotador" can be used by below-elbow amputees with osseointegration, restoring one degree of freedom without requiring any training or electronic components. This unique advantage of osseointegrated implants compared to socket suspended prostheses allows for better use of the prosthesis in everyday life, which is what we are currently testing for in the device. This project is conducted in collaboration with Integrum AB.

TRANSFEMORAL (ABOVE-KNEE) BIOMECHATRONIC PROSTHESES

Most leg prostheses are purely mechanical and are attached by a compression socket over the residual limb. Since the prosthesis is separated from the neuromuscular system it leaves the user with poor control of the prosthetic joints below the level amputation. Furthermore, the socket attachment often leads to discomfort and skin disorders due the heavily loaded soft tissue and poor mechanical attachment of the prosthesis. In this project we aim to solve both of these problems by replacing the socket with direct skeletal attachment by means of an implant directly attached to the bone, and by using implanted electrodes in muscles and nerves of the residual limb to record bioelectric signals from the user. The signals are then processed and converted to control signals providing the user with full volitional control of the prosthetic leg in real time.

Currently, work is being done to prepare for the first clinical application of this technology in the lower limbs. The system developed within this project will provide unprecedented prosthetic control for lower limb amputees, leading to functional ability approaching that of an intact limb. This technology has the potential to substantially reduce the disability of a lower limb amputation and to greatly improve the quality of life for its users.

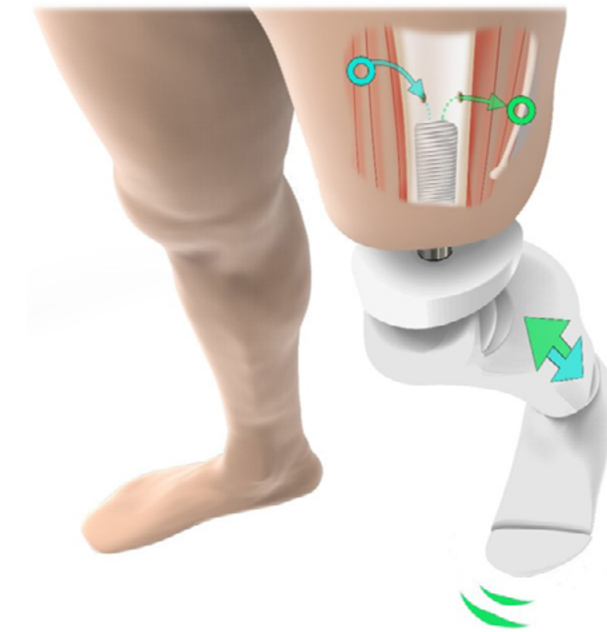


Photo above
Biomechatronic prosthesis with our osseo-neuromuscular interface for above-knee amputations.

EMBODIMENT OF A PROSTHETIC LIMB

Losing an arm significantly changes how you interact with your surroundings – you suddenly cannot reach out, grab, feel, and move an object the way you were used to. At BNL we aim to make it possible for amputees to use a prosthesis that is more than just a technical device and is perceived as part of their own body, therefore we need to develop a technological solution so that natural interaction with their environment is possible again. Two aspects are crucial for patients to experience their prosthesis like a real biological limb: being in full control of initiating and executing a limb movement (agency) and perceiving that the moving limb is part of their own body (ownership). We are currently developing experiments to test if the amputee patients developed a sense of agency and ownership towards our prosthetic limb solution. For example, we investigate if sending neurostimulation pulses to elicit a touch sensation every time the prosthesis is touched results in the amputee patients feeling said touch on a part of their body, instead of just seeing their prosthesis being touched. The results of the experiments will show how close our prosthetic system comes to being perceived as a replacement for the lost biological limb. And even more importantly, the results will provide information on where we can improve our system so that patients truly perceive their prosthesis as part of their own body.

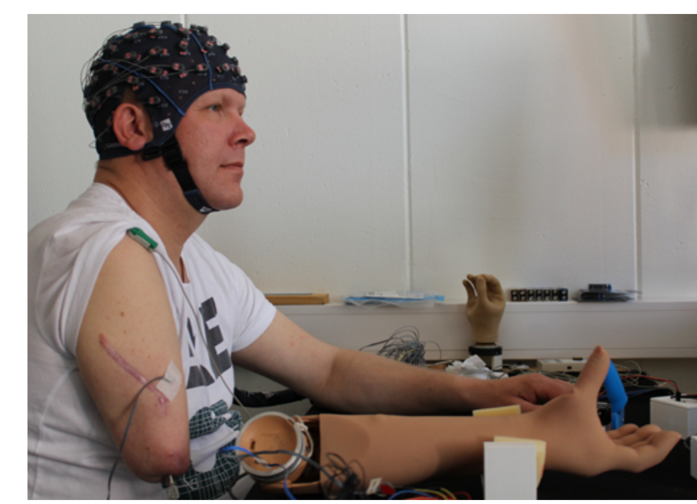


Photo above
Subject participating in a study exploring the embodiment of a prosthetic limb when near-natural sensory perception is available.

NEURAL CONTROL AND SENSORY FEEDBACK

EXTRACTING MOTOR VOLITION FOR INTUITIVE CONTROL

We strive to provide patients with natural control over their artificial devices. This can be achieved in a few different manners which are often complementary, such as using decoding algorithms along with surgical interventions. Dr. Ortiz Catalán released in 2013 the first open source and integrated software platform for the decoding of motor volition using bioelectric signals, named BioPatRec. This research platform allows development of algorithms, with a seamless implementation, in the fields of signal processing, feature selection and extraction, machine learning, and real-time control. It includes all the necessary routines for the control of virtual and robotic limbs, as well as real-time evaluations. It has been further developed over the years at BNL integrating new algorithms and features, and recently supplemented with an open source bioelectric hardware acquisition system (ADS BP), both freely available at github. The motivations for this work were several: 1) allow for an unbiased comparison of the wealth of algorithms proposed for prosthetic control; 2) foster collaboration, allow repeatability, and reduce unnecessary repetition of common code; and 3) create of a common repository of bioelectric signals related to limb motions. In addition to our development of algorithms for proportional and simultaneous control of artificial devices, we work closely with surgeons locally and abroad to integrate innovative nerve transfer and neuromuscular reconstructive techniques such as targeted muscle reinnervation (TMR), regenerative peripheral nerve interfaces (RPNIs), and agonist-antagonist myoneural interfaces (AMIs).

SENSORY FEEDBACK

Similar to our approach to control, we focus our work on providing intuitive sensory feedback to close the loop in the operation of artificial devices. We are particularly interested in direct peripheral nerve stimulation, owing that exciting afferent neural pathways (towards the brain) produces sensory experiences perceived as originating in the missing limb. We are currently conducting exhaustive and rigorous evaluations on the long-term safety and psychological perceptions resulting from neurostimulation. Furthermore, we are investigating the effects of different stimulation paradigms in perception and prosthetic function. Thanks to our osseo-neuromuscular technology, we have the unique opportunity to explore the effect of providing neural sensory perception while operating a prosthetic hand in daily life. We take pride in the development of the first, and currently only, neuroprosthetic system that allows patients to feel with their prosthetic hands while performing activities of daily life. Several of our patients have been fitted with such a system and have used it safely for years.

Photo right

Subject with the first biomechatronic prosthesis that allows for control and sensory feedback using implanted electrodes in activities of daily life. Sensors in the hand provide information to the subject on grip force. Said information is perceived by the patient as originating from the missing hand.

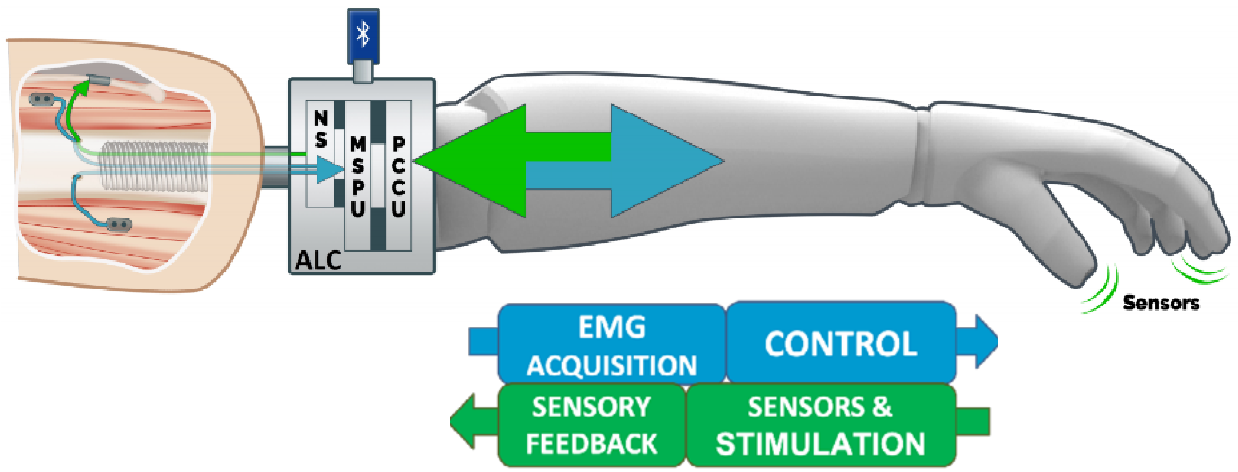


Photo Above

Embedded Artificial Limb Controller (ALC) for natural control of prosthetic arms with sensory feedback.

THE ARTIFICIAL LIMB CONTROLLER (ALC)

An embedded electronic system was deemed necessary to be able to provide the natural control with sensory feedback aforementioned in a self-contained prosthetic system that patients could use safely and reliably at home. We therefore developed a prosthetic controller capable of translating the signals from the implanted electrodes into intuitive prosthetic movements, and further, to provide direct neural feedback consistent with tactile (touch) information measured at the prosthetic hand. This controller was designed to be robust enough for daily use, as well as flexible enough to allow further research and investigations.

Our Artificial Limb Controller (ALC) is a wearable embedded system mechanically and electrically compatible with our osseo-neuromuscular technology. Its shape and dimensions make it suitable for both above- and below-elbow levels of amputation. The ALC can decode the user's motor intent via machine learning algorithms and conventional direct control. Moreover, it includes a neurostimulator that is used to translate the information available from sensors on the prosthetic hand into electric pulses directed to the neural electrodes. The ALC has other features such as inertial sensors, wireless communication, SD card, UART, SPI and CAN bus, and six outputs for controlling DC motors.

Our osseo-neuromuscular technology combined with the ALC is currently the only prosthetic system in the world that can provide reliable control and tactile sensory feedback using implanted electrodes in daily life. This combination is a breakthrough in in a field that, despite all the research efforts of the last decades, is still struggling to translate new solutions into clinical reality.

Photo right page

Subjects with biomechatronic prostheses using implanted electrodes for control and intuitive sensory feedback in activities of the daily living unsupervised by the research staff. This is possible owing to the stability of the osseo-neuromuscular interface and our development of an artificial limb controller (ALC)

DECIPHERING AND TREATING PHANTOM LIMB PAIN

ORIGINS AND TREATMENT OF PHANTOM LIMB PAIN

Patients can develop neuropathic pain after traumatic events such as limb amputations or nerve injuries. One such pain is Phantom Limb Pain (PLP), which can considerably reduce patients' quality of life. Dr. Ortiz Catalán developed a novel treatment for such neuropathic pain induced by motor impairment and/or sensory deafferentation, such as in the case of amputation, nerve injures, or stroke. Originally developed for subjects with amputation, this treatment known as Phantom Motor Execution (PME) relies on the decoding of phantom motor volition via myoelectric pattern recognition and real-time feedback via virtual and augmented reality. Initial clinical evaluations have shown PME to be effective in patients with chronic intractable PLP, and this technology has been further developed at BNL to cover both, upper and lower limb amputations.

More recently, Dr. Ortiz Catalán proposed working hypotheses for the origin of PLP and working mechanisms of PME. Current ideas on the origin of PLP are either challenged by clinical observations or lack a direct link to the neural circuitry responsible for pain perception. The stochastic entanglement of the pain neurosignature with impaired sensorimotor circuitry has been put forward by Dr. Ortiz Catalán as a potential explanation for the etiology of PLP. At BNL, we aim to test this and the PME hypothesis to potentially elucidate the underlying mechanisms of neuropathic pain such as PLP. We are performing brain imaging studies on patients undergoing PME and control therapies in the search of pain neural correlates. The results of this work can provide a deeper understanding of neuropathic pain and help in the development of its treatment.

Photo right page

Phantom Motor Execution (PME) as a treatment of PLP. Phantom movements are decoded using surface EMG via machine learning algorithms to be then showed in real-time using augmented reality.

AN INTERNATIONAL, DOUBLE-BLIND, RANDOMISED CONTROLLED CLINICAL TRIAL ON PHANTOM LIMB PAIN

There is no consensus on the treatment of PLP; an approach that comes through as beneficial for one patient might be of no use for another. This is clearly reflected in the scientific literature where only a minor portion of the staggering number of proposed therapies is constituted by randomized controlled trials (RCTs), the golden standard of clinical evidence. Phantom Motor Execution (PME) has been proven valuable for patients with chronic intractable PLP. However, in order to gather a higher level of evidence, it is necessary to test the method with an RCT. This is the objective of one of the projects currently led by BNL, which is advanced by the collaborative endeavor of nine investigational sites in seven different countries. The RCT, enrolling at the time of issue of this brochure, compares in terms of pain reduction the efficacy of PME against an active control intervention in a double-blinded fashion. Moreover, the involvement of a large number of participants (>60) is meant to provide the power necessary for meaningful and generalizable conclusions. This is a major effort to bring more clarity in a field, namely PLP research, where many basic questions have been unanswered for decades. Finally, if proven efficacious, PME has the potential to become an integral part of much needed guidelines for treating patients suffering from PLP.

Photo above

A patient performs PME using the Augmented Reality using the Phantom Limb Pain therapy system in the clinic

OUT OF THE CLINIC AND INTO THE HOME

Looking ahead from the currently ongoing clinical trial of PLP, the next step for the PME therapy is to take the technology out of the clinic for the patient to perform the therapy at home. We hypothesize that home therapy yields efficacious results in pain reduction comparable to findings observed in the clinic, with the advantages of independent use outside of the hospital, as patients adapt the therapy according to their individual preferences and lifestyles. The home use study aims to explore the benefits and the translational challenges encountered in the transition from clinic to home use. The Phantom Motor Execution device is currently being used at home by a few patients who act as a series of case studies for the use of PME as a self- treatment strategy for PLP. The home use study is a collaborative effort between researchers at BNL with backgrounds in the anthropology, engineering and user interface design in order to holistically understand the use, efficacy, and domestication of this therapy and its technology in home contexts.

Photo above

A patient performs PME in the comfort of his home

Photo Left

EEG system used for studying the neural basis of phantom limb pain.

STUDYING THE NEURAL BASIS OF PHANTOM LIMB PAIN

Even though the rapid technological improvement of non-invasive neuroimaging techniques has allowed tremendous advances in the understanding of how the nervous system functions in health and disease, many questions remain unanswered and the road to a complete understanding of how the brain works is long and convoluted. However, techniques which allow for greater understanding of the structure and function of the brain hold the promise of bringing clarity to many of the unsolved problems in neuroscience. One such problems is the current lack of comprehensive understanding of how the brain changes following a traumatic event such as an amputation. It is hypothesized that neural changes that occur after amputation are at the origin and maintenance of PLP, nonetheless the nature of these changes remains elusive. Starting from this question, we seek a mechanistic explanation of PLP by studying not only how the brain in pain differs from a healthy one, but also how PME contributes to brain plasticity and its relation to pain relief. The techniques used in this investigation are functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) as they complement each other in terms of spatial resolution, superior in fMRI, and temporal resolution, superior in EEG, to give a more accurate picture. The answers coming from this project would not only advance the scientific knowledge about the rules organizing the perception of the body and the experience of neuropathic pain, but also promote efficacious pain management approaches that target specific mechanisms known to be at the root. This project is conducted in collaboration with resarchers at Gothenburg University and Sahlgrenska University Hospital.

BIOELECTRIC SENSORS

GRAPHENE-BASED FLEXIBLE NEURAL INTERFACES FOR THE CONTROL OF NEUROPROSTHETIC DEVICES (GRAFIN)

Due to its strength, high conductivity, and biological compatibility, graphene makes an apparently ideal compound for use in electrodes to interface with biological tissue. It has potential application in implanted and surface electrodes for both measurement and stimulation of nerves and muscles. However, limited research has been done on using graphene-based electrodes in human-machine interfaces, such as for the control of prosthetic limbs. This project aims to investigate graphene-based electrodes for closed-loop control (control with sensory feedback) of prosthetic devices. Different designs of graphene-based electrodes will be designed and compared to textile-based and traditional silver/silver chloride electrodes in a high precision bench test, and in able-bodied subjects and subjects with amputations using BioPatRec, a platform developed by our group that mimics the control systems of prosthetic devices. This is the specific contribution of our team in this European project funded by VINNOVA under the recommendation of the European Commission granted by the FLAG-ERA Joint Transnational Call 2017. This project includes the Universitat Autònoma de Barcelona, the Catalan Institute of Nanoscience and Nanotechnology (ICN2), Boğaziçi University, and Chalmers University of Technology.

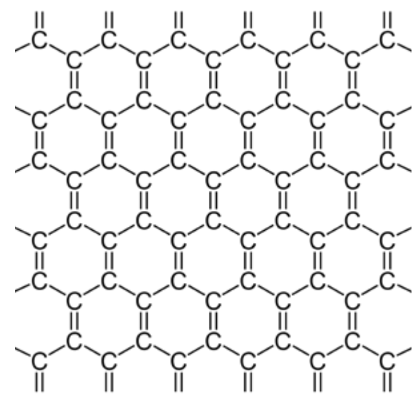
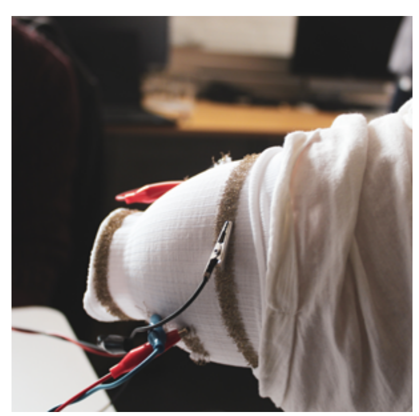


Photo above

Chemical structure of Graphene

TEXTILE ELECTRODES

A great deal of development has occurred in the past few decades to allow electronics for body monitoring to be worn comfortably on the body. New methods for developing smaller microprocessors, lower power devices and new techniques for creating flexible fibers for electrical wiring in the textile industry have contributed to creating opportunities for new applications in the wearable market. Using textiles as sensors for biometric monitoring, in our case for acquiring surface electromyography signals (sEMG), would increase user comfort because textiles are often more flexible and have a potential for long term or everyday use. Textile sensors for sEMG acquisition are also reusable and a more sustainable solution to biometric monitoring when compared to the traditional adhesive silver chloride electrodes often used in surface electromyography acquisition.A currently ongoing feasibility study investigates how we can use textile electrodes can be used in at-home biometric therapies and prosthetic control. The textile electrode project is a collaborative project with the Smart Textiles Design Lab at the University of Borås.



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Textile electrodes used to acquire sEMG signals

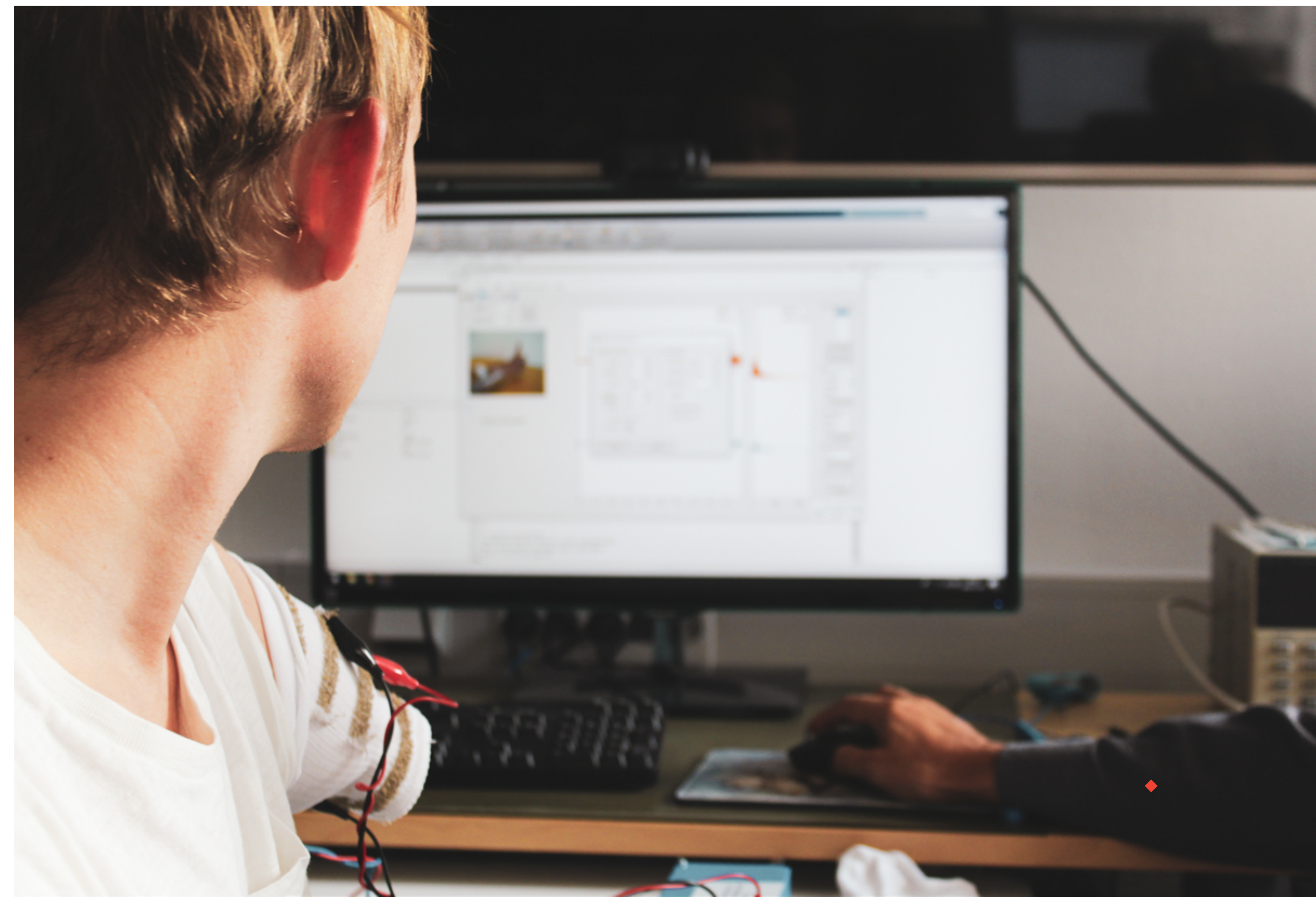


Photo above

Testing the textile electrodes placement and signal quality

NEUROREHABILITATION STROKE AND SPINAL CORD INJURY

FUNCTIONAL TRAINING AND REHABILITATION

Undamaged neurons after a stroke or spinal cord injury (SCI) have the ability to form new connections and regain much of the functionality lost immediately after the injury. Without exercise and direction, this repair process (called neurorehabilitation) will quickly stagnate, and much functionality may be lost indefinitely. When combined with traditional occupational therapy, the use of residual muscle signals (via EMG) and visual feedback has the potential to dramatically improve rehabilitation outcomes. This project focuses on the use of EMG-based visual feedback during therapy to drive neurorehabilitation and increase patients' ability to perform activities of daily life independently. This technique will be used in a clinical trial to compare its effectiveness to traditional rehabilitation in restoring patients' motor control. Success will have a direct positive impact on patients' level of independence and quality of life and result in a significant reduction in healthcare-related costs.

Photo right page
Adam Naber sets up the functional training sEMG system on a patient in Japan

A MEDICAL ANTHROPOLOGICAL STUDY OF HUMAN-MACHINE INTERFACE PROSTHETICS

Photos above

Patients with biomechatronic prostheses using technology developed at BNL with tasks of daily living

Medical anthropology is the study of how health, illness and medicine are dynamically shaped and experienced by cultural, relational, historical, and political forces. Anthropology of science and technology examines the significance of particular cultural, political, and economic contexts on the production of scientific knowledge, created by human actors. This project synthesizes these two fields to explore the dynamic interchanges occurring among patients, engineers, and clinicians in the development of neuroprosthetic technologies. The prosthetic technologies engineered by BNL enable patients to move their prosthetic limbs intuitively while also receiving sensory feedback (touch) from the environment back into the body. Yet such sensations remain deeply subjective experiences, requiring a delicate process of communication, collaboration, and translation among patients, scientists, and engineers. How do patients' sensory experiences—their sense of being in a body in space, and their awareness of their phantom limb—influence the development of such biotechnologies? How do patients actively participate, and even intervene, in the design of their human-machine interfaces?

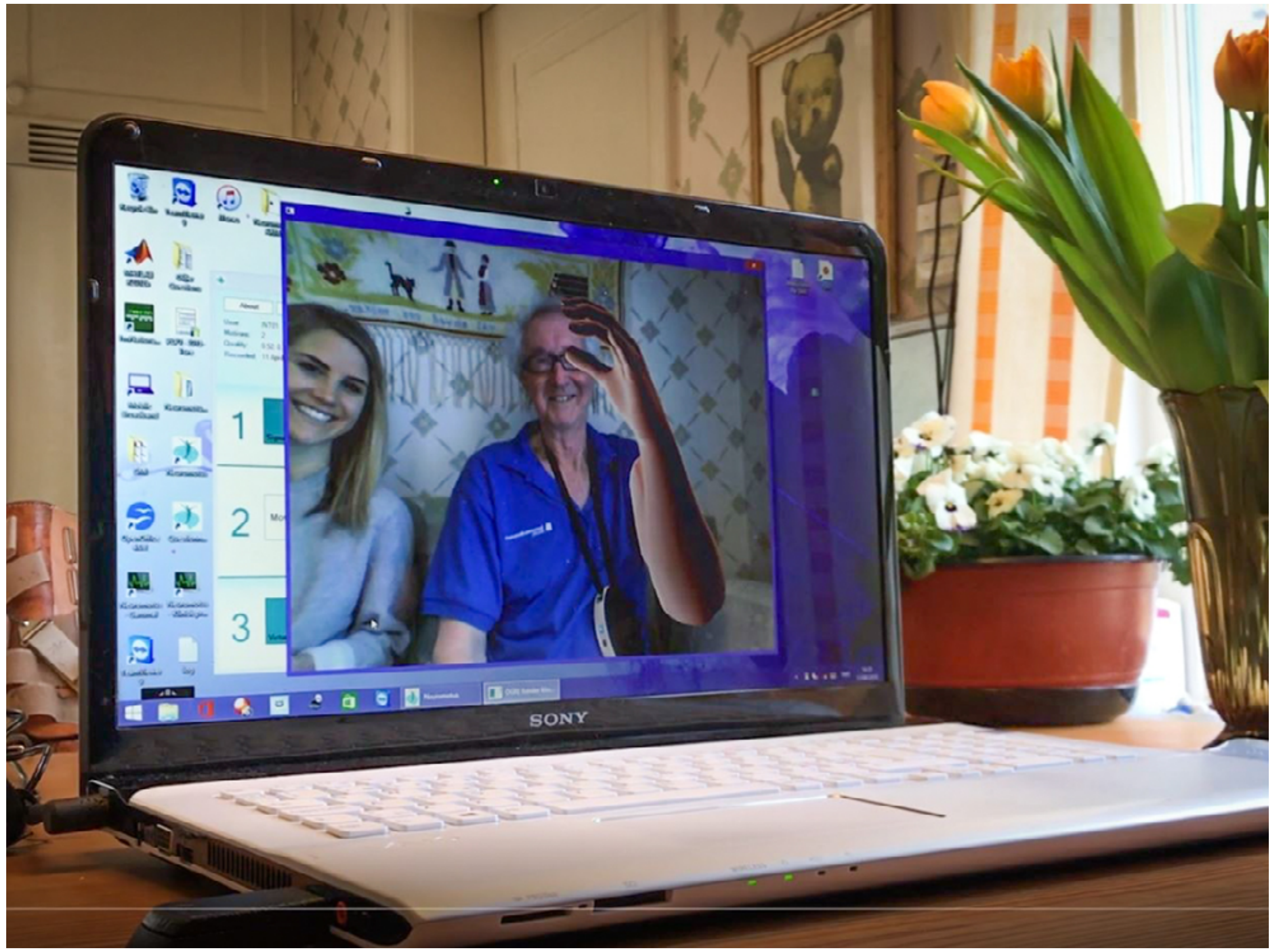


Photo above

Anthropologist Alexandra Middleton visits patients in their home and observes the use of the technology developed at BNL in everyday life

Anthropologist Alexandra Middleton, a doctoral student at Princeton University and visiting researcher at BNL, investigates the idea that patients are simultaneously experimental subjects and active co-innovators in human-machine interface design. She employs ethnographic research—in depth interviews and long-term participant observation—to understand the social landscape of the laboratory, clinical, and in-home settings in which these technologies are developed and used. As these devices are the first in the world of their kind to travel outside the laboratory for home use in everyday life, ethnographic focus is placed on the home as a key site of science-in-the-making. Spending time with patients and their families in their homes, Middleton investigates how everyday experiences constitute a particular type of expertise about the use and possibilities of these devices. Circling back to the clinic and laboratory, Alexandra traces how these forms of expertise inform decisions in design as well as therapeutic communication. Findings from this research will offer insight into the ways science is made both within and outside laboratory and clinical walls, highlighting the importance of involving disabled individuals in the design of technologies aimed at enhancing their lives. These insights will inform clinical trial design and practice among scientists, clinicians, and patients, as well as broader publics interested in human-machine relations.

OUR FUNDING AGENCIES

Our funders have enabled our passion to materialize in scientific and medical engineering outcomes, and it is essential for further pursuing our work. We are extremely thankful for their trust and support in the past and coming years!

Stiftelsen Promobilia

>500,000 EUR from 2015 to 2020. The Promobilia foundation aims to promote the development of technical aids to enable a more active life for people with disabilities. It has been instrumental for the establishment of BNL by supporting several of our projects, as well as one of our PhD students. We observe remarkable alignment between the purpose of the Promobilia foundation and our vision at BNL.

Vinnova (Medtech4Health and SWElife)

~650,000 EUR from 2017 to 2020. The Swedish Innovation Agency (VINNOVA) has as its vision to strengthen Sweden as a country of research and innovation. It has supported the research by BNL's founder since 2009, and more recently BNL's translational research to clinically implement technologies developed in collaboration with our medical and industrial partners via the Medtech4Health and SWELife programs.

European Commission via FLAG-ERA / VINNOVA

~199,000 EUR from 2017 to 2020. Aimed to support the European Graphene Flagship initiative, FLAG-ERA via VINNOVA is financing BNL as part of the project: GRAFIN (GRAphene-based Flexible neural Interfaces for the control of Neuroprosthetic devices). The GRAFIN project aims to develop graphene based neural electrodes for use in the bidirectional control of an advanced bionic prosthesis.

Britt and Arne Lundbergs Foundation

~500,000 EUR from 2018 to 2020. The purpose of the Britt and Arne Lundbergs Foundation is to promote scientific medical research. Thanks to its generous donation, BNL is currently being furnished with equipment to enable the development, implementation, and evaluation of osseo-neuromuscular prosthetic limbs.

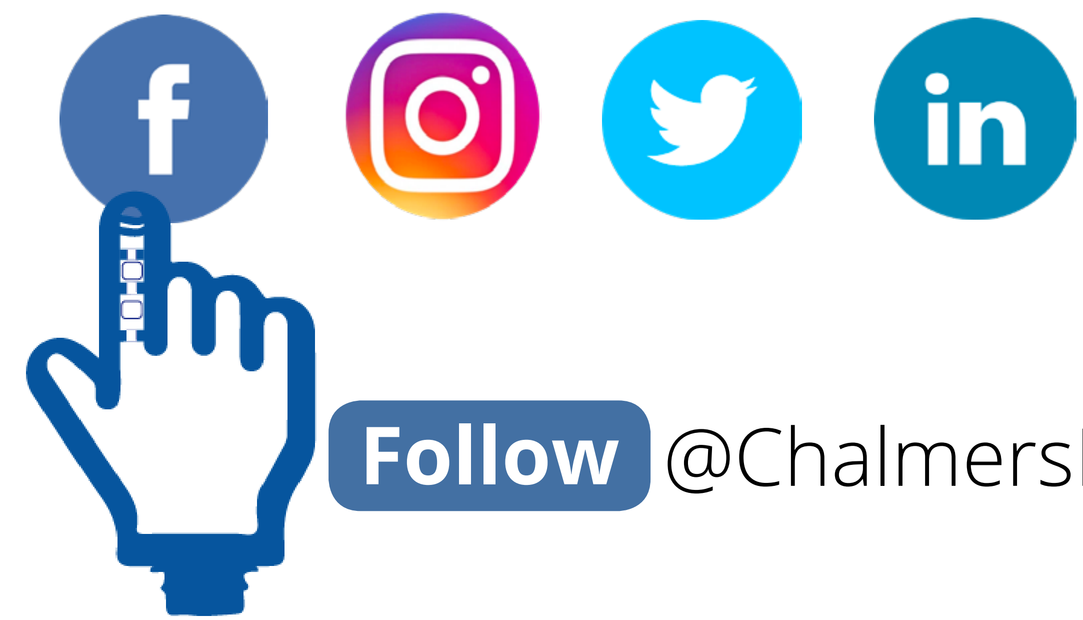
Swedish Foundation for Strategic Research

~230,000 EUR from 2016 to 2020. The objective of the Swedish Foundation for Strategic Research (SSF) is to support research that strengthens Sweden's competitiveness. It has supported and Industrial PhD project between BNL and Integrum AB aimed to developed lower limb, osseo-neuromuscular prostheses.

Vetenskaprådet

~200,000 EUR from 2014 to 2018. The Swedish Research Council (Vetenskapsrådet) is Sweden's largest governmental research funding body and supports research of the highest quality within all scientific fields. It has founded an Industrial PhD project between BNL and Integrum AB aimed to develop an embedded system for intuitive control of artificial limbs with sensory feedback.

GET INVOLVED!



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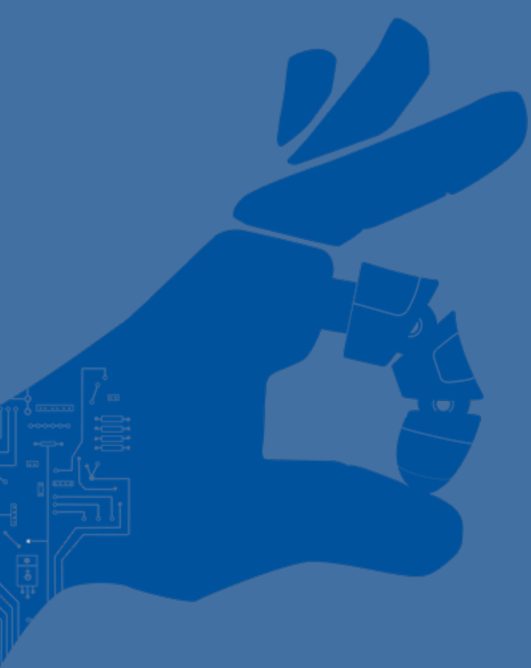

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