EIT Digital DOCTORAL SCHOOL

EIT Digital Doctoral School– Industrial PhD position proposal

Neuro-affective Computing: Emotion Recognition via Non-Invasive BCIs for Interactive Systems

Industrial partner	GTEC (www.gtec.at)
Industrial Advisor	**Dr Christoph Guger** studied biomedical engineering at the University of Technology Graz and Johns Hopkins University in Baltimore, USA. He then carried out research work at the Department of Medical Informatics (Prof. Pfurtscheller) at the University of Technology Graz and received his PhD in 1999. He founded GTEC in Schiedlberg, AT in 2004, and has been the co-CEO since then along with Dr. Guenter Edlinger. Dr. Guger has dozens of peer-reviewed publications, including several Open Access publications in Frontiers in Neuroscience that he led or co-authored. Dr. Guger has a good history of including PhD students at GTEC in publications. For example, Murovec et al. (2020) was just published in Frontiers in Neuroscience. Ms. Murovec is a full-time GTEC employee and PhD student, and this paper is part of her PhD work as well as her contribution to a collaborative funded project called ComAware. Dr. Rupert Ortner has several publications about BCIs to control orthoses for assistive devices and completed his PhD while working at GTEC. Dr. Ortner was then promoted to the Manager of GTEC's new office in Barcelona and has continued publishing with Dr. Guger and new PhD students. Dr. Guger has earned numerous awards, including the internationally recognized EY Entrepreneur Award, Microsoft Innovation Award, and Fast Forward Award. He has managed GTEC's participation in over two dozen collaborative projects, always involving hardware, algorithms, and/or software for real-time EEG or multimodal signal analysis. Dr. Guger has also managed eight full-time employees who were or all PhD students, usually at the nearby Johannes-Kepler University. He has strong experience with projects that involve hosting and training visiting researchers, including the MSCA-RISE and MSCA-IF mechanisms. Sierningstrasse 14 4521 Schiedlberg Austria

Academic/research partner	University of Trento, Department of Information Engineering and Computer Science (https://disi.unitn.it/)
Does the academic partner grant the PhD Degree?	**Prof. Luca Turchet** is a computer scientist with expertise in the fields of music technology, internet of things, affective computing, human-computer interaction, and machine learning. He is an Assistant Professor at the Department of Information Engineering and Computer Science of University of Trento where he leads the Head of the Creative, Intelligent and

	Multisensory Lab. He received master degrees in Computer Science from University of Verona, in classical guitar and composition from Music Conservatory of Verona, and in electronic music from the Royal College of Music of Stockholm. He received the Ph.D. in Media Technology from Aalborg University Copenhagen and held postdoc positions at KTH Royal Institute of Technology and at the Centre for Digital Music of Queen Mary University of London. His scientific and entrepreneurial research has been supported by numerous grants from different funding agencies including the European Commission, the Italian Minister of Foreign Affairs, the Danish Research Council, and UK Arts and Humanities Research Council. He published more than 80 scientific publications in top tier journals and leading international conferences, as well as he holds 2 international patents. Via Sommarive 9 38123 Trento Italy

PhD project information

PhD Thesis – Title	**Neuroaffective Computing: Emotion Recognition via Non-Invasive BCIs for Interactive Systems.**
PhD Thesis – Short summary	This project will develop new knowledge and a complete practical software platform to develop new interactive applications using Brain-Computer Interface. The adaptation of the interactive applications will be based on the user's mental state, which will be classified in real-time using the electroencephalogram (EEG). The PhD Project is not focused on the hardware side, but the software potential to process the brain signals in a more optimal way to improve Signal to Noise ratio, and extend the capacity of the algorithms to provide more advanced functions and create new applications that are not in the market yet. GTEC is currently developing applications to support next-generation motor rehabilitation therapy by helping patients regain movement after stroke using a brain-interface that can allow patients to connect with robots, VR systems or other tools used in therapy. This project will develop a novel suite of real-time software tools, with supporting adaptive machine learning algorithms, that will extend this approach to allow direct control of robots, a haptic glove and improved feedback. Furthermore, if the processing of the signals can be improved by advanced algorithms that are part of this PhD, the recovery of patients can be further improved in terms of time required and the extent of recovered function. In addition to new and scalable software tools, this project could lead to new services for professional companies specialized in motor rehabilitation therapy. Concrete PhD activities will include: 1) Exploring the technological and business conditions for industrialising the developed prototype system and creating a spinoff with the support of EIT Digital (e.g. applying for an innovation activity call). 2) Developing detailed specifications and scientific protocols;

	3) Writing and improving real-time software for tasks including data analysis, protocol management and providing user-centered feedback; 4) Developing two use cases detailed below; 5) Collecting EEG data from healthy human participants and stroke patients using practical, real-world, wireless, dry electrode systems; 6) Developing different algorithms and parameters to classify different user states from the EEG and other data; 7) Analysing EEG data and classification results for scientific and public dissemination; 8) Working with framework conditions and quality control; 9) Writing and submitting two top-tier journal articles for peer-review; 10) Presenting project work at two or more international conferences; 11) Managing ethical issues with healthy human participants; and Main technologies include: Human-computer interaction (HCI), mathematical models, EEG, neuroscience, computer science, programming, cognitive psychology. The development of the new algorithms will use AI tools such as machine learning, "Big Data" analytics and advanced statistics to look for optimal solutions that can allow to work with the three proposed scenarios that can open new services for stroke therapy, assistive devices and other markets. Regarding novelty, prior work has explored how to adapt different applications based on motor activity. Some of this work has involved EEG, and has even sometimes included real-time adaptation. However, most work with these BCI approaches is sparse and – more importantly – limited to laboratory settings without patient involvement. GTEC is the only company that produces an EEG-based BCI system that is meant for stroke patients and their therapists, which has been used widely since 2016. This project has the potential to significantly impact on GTEC's business line. GTEC already sells both components and systems for stroke rehabilitation and assistive devices. This project could lead to a new suite of systems and components that impact very broad market of stroke patients, as well as IP, spin-off applications for patients, new partners and other commercial benefits. On the other hand, if this project does not lead to a successful product, GTEC will continue to grow through its other products.
No. of PhD positions – maximum 2 (if 2 positions, then please differentiate them)	1
PhD duration	3
Innovation Focus Area:	Digital Wellbeing

Doctoral Training Centre location	Trento

Co-finance scheme for Doctoral Programme Costs

Co-funding percentages:	

- Industry - Academia - EIT Digital -Other Source (e.g. gov. funds)	50% 0% 50% 0%

PhD thesis motivation and innovation valorisation

Rationale/challenge	**Hardware for practical EEG systems:** The state-of-the-art (SOA) for real-time collection of EEG data from people has been changing rapidly. Until recently, most EEG systems were not practical outside of laboratory settings for many reasons. Electrodes required messy electrode gel and cables connecting the cap to a computer. Real-world noise sources created unacceptable noise in the EEG signal. Caps were not cosmetically appealing and cost several thousand euros. Due to the limited options with hardware, there was fairly little effort to develop tools to support new applications and software for mainstream users. The SOA is very different today. GTEC sells wireless systems that do not require gel that are much more robust to noise. The wireless systems do not have cables that limit the user's mobility and can get caught on other equipment, and are much smaller and lighter than earlier systems. GTEC's new Unicorn Black system (https://www.unicorn-bi.com/) is designed to look "cool" for mainstream users and can provide good signals for only one thousand euros. Perhaps most importantly for this project, the Unicorn system is designed to be modified and "hacked". Algorithms, software and applications are easy to design and modify. GTEC has committed to ongoing improvements to its Unicorn products for the next several years. Hence, this Unicorn Black system is very well suited to this proposed project. The project will not need to devote resources to hardware development. **Software for practical EEG systems:** Instead, the industrial research will focus on the software development and the human-computer interaction aspects, by optimising current solutions towards the real-time usage and devising novel interaction paradigms to be applied in new application scenarios. Software is also an area where EEG applications are fairly weak. Most software is developed for laboratory applications. There is little emphasis on usability and HCI considerations for non-expert users outside of the lab. Validation with end users, including usability testing, is usually ignored. In particular, end users with special needs (such as stroke patients) are often ignored until the system is complete. Software for mainstream EEG applications is becoming more advanced as public and commercial interest in EEG grows. GTEC has extensive software libraries to support data recording, data tagging, numerous pre-processing, analysis and classification activities, data visualization and reporting, secure storage and other tasks. GTEC's software tools operate in real-time and follow standard guidelines and procedures for usability testing. This is relevant because the PhD student will be able to quickly develop advanced software applications, and conduct usability testing with healthy persons, without excessive development time.

	Hence, the PhD student will learn to develop software, and work with cutting-edge hardware, to capitalize on the emerging trend of EEG systems for mainstream users in real-world settings.
Innovation	The intended solution – and the main goals of this project – are to produce (1) knowledge and (2) a complete system for adaptive EEG-based systems based on emotion, across three specific use cases. These two goals will comprise: • New/improved algorithms, parameters, processing chains and other details to manage EEG data and extract information about user state while trying to accomplish goals during the interaction with a system; • Interactive, user-friendly software to help users (1) manage their EEG system, including quick mounting, maintenance and troubleshooting; (2) select the type of task, task parameters etc; (3) monitor their own EEG activity such as the intensity of their imagined grasping after the therapists asks to imagine grasping; (4) develop their own user-state adaptation programs and (5) print or email reports. • A Business Plan within the PhD thesis that evaluates commercial aspects with respect to post-project opportunities, including three recommended directions. The three use cases are in three different markets: **Haptic feedback:** We will explore wearable items such as gloves, hats and shoes that can provide haptic feedback based on users' emotions. **VR environments:** We will create new VR systems with backgrounds and environments that adapt to emotions, such as by changing colour, brightness, images or patterns or modifying the soundscape. **Home robots:** We will develop a system to control a robot that adapts to users' emotions. We will explore different robotic options, including humanoid robots, orthoses and assistive pets. GTEC has many different robotic devices available for testing. We will explore two applications, including use case analysis: **Stroke rehabilitation:** About 15 million people suffer from a stroke each year worldwide, and about half of stroke survivors are left with permanent movement disability. In the EU alone, over 8000 entities provide therapy for stroke, ranging from small, specialized therapy centers like the RecoveriX-Gyms to major hospitals. Hence, stroke rehab is a very large market. All three use cases could be relevant. GTEC's RecoveriX system already includes VR tools, but they do not adapt to emotion. Orthoses with haptic feedback could also foster faster and more effective treatment, saving time and money and increasing the number of patients that might benefit. This work could lead to improvements to the core RecoveriX system, optional RecoveriX software modules and/or spin-off software options. Many therapists already own and use robotic orthoses, and some have haptic gloves. We will also consider strategic partnerships and "bundling" with third-party device manufacturers. Many of GTEC's products include support for

	third-party devices. For example, GTEC sells a software module that enables buyers to use data from eye-tracking systems from all major manufacturers with GTEC products in real-time. Buyers can purchase a complete EEG system – including third-party eye-trackers – directly from GTEC. **Assistive devices:** Movement rehabilitation training is only feasible for some persons with motor disabilities. Stroke patients only have damage in the brain, and their remaining motor pathways are generally healthy. However, movement rehabilitation is not possible for persons with some birth conditions, injuries or progressive diseases that disable the arms. For these persons, the best way to provide benefit is through artificial limbs. But, how do you control an artificial limb? Advanced methods today rely on residual activity from the shoulder or the closest intact area, which provides only limited control. Activities like grasping, throwing, typing and most dextrous movements are not possible. We will explore improved tools to control assistive robotic devices. GTEC already has several publications on this topic and sells products (such as the IntendiX system) for home use of assistive devices and robots. We will aim toward more accurate control and broader options – that is, allowing users to perform more different tasks with an existing device. Haptic gloves and VR environments could both provide improved multi-modal feedback to help train users and feel feedback from the glove when they touch objects. We will use "high level control" in which a single thought – i.e, command through the BCI – can implement a sequence of actions. This will provide more flexible and powerful tools that could be sold as a software add-on to existing GTEC products or support improved services for disabled persons.
Expected academic - outcomes	The academic outcomes will include: • Two peer-reviewed Open Access publications; • Two conference presentations, which may be talks, posters, publications, demonstrations, etc as appropriate; • Five professional public interactive workshops/demos; and • A completed PhD thesis. The interactive workshops/demos are a unique academic and industrial dissemination mechanism. The PhD student will plan, organize and execute five workshops that will each occur at a different host institution (such as a well-known university or research centre) and/or academic and industrial event (such as a conference, a fair, or the EIT Digital demo days). While workshops with lectures and slides are common, these workshops will be unique because of hands-on, interactive EEG demonstrations with participants. At each workshop, attendees can don an electrode cap, see their own EEG, and actually use prototype versions of our new tools in this project. This first-hand experience with adaptive EEG systems is hard to provide through papers and talks, and is an excellent way for the PhD student to develop a reputation and new professional contacts. GTEC has organized over 250 hands-on EEG workshops across over 15 years, and will contribute its knowledge and materials to this project. These academic activities will be bidirectional. That is, we will learn from others and not just tell them information. We will develop and use surveys to learn more about user needs, preferences and suggestions. These surveys will support academic outcomes (several BCI publications present surveys of

	end-users), revisions to our system within the project and future advertising. We will ask experts for advice from medical, scientific, technical and commercial angles, depending on their knowledge. We will seek potential future research collaborators, buyers, strategic partners and other stakeholders that could help us during and after the project and also improve the PhD student's network of connections.
Concrete innovations expected as the outcome of the proposal -	We expect the following innovation outcomes as the result of the PhD project: • A novel dataset of EEG signals with precise data tags (synchronized at the millisecond level) that will provide data for the PhD student and for our software tools; • Three prototypes of a novel software tools that run on existing hardware. Components of these prototypes will be subsequently engineered and integrated into industrial partner products; • Creation of a successful collaborative project between the academic partner and the industrial partner, which will strengthen the relationship between the two partners and also result in internships of EIT master students; • Market analysis, risk analysis, financial and technological analysis for the industrialisation of the developed prototypes with the aim of creating a spinoff with the support of EIT Digital (e.g. applying for an innovation activity call). Our plan involves three prototypes: initial (M12); advanced (M24) and final (M36). The initial version will be used for testing starting in M13, and the advanced version will have more features and upgrades for testing. Our testing within the project will provide data, technical logs, and feedback that we can use within the project to improve our prototypes, research new algorithms and parameters, help the PhD student progress toward the PhD and develop material for dissemination. The final prototype can be used for post-project testing and improvement, and thus developed into a product for sale six months after project completion. Based on the results from testing use cases, and our commercial research, we will recommend three post-project markets and applications. These may span multiple use cases and will consider options for GTEC as well as spin-offs or franchisees. These recommendations will be included in the Business Section of the PhD thesis. The testing phase can occur at both GTEC and Trento. Both partners can work with healthy persons. GTEC and Trento both have ethical approvals for healthy user evaluation. GTEC has direct access to stroke patients through its RecoveriX-Gym (which is attached to the main GTEC office) and ethical approval to work with them. GTEC also has very strong experience managing confidential data from healthy persons and patients. Many projects require secure data management, so staff are familiar with software and procedures to ensure confidentiality. GTEC has a very secure data storage infrastructure. GTEC's server is inside a locked cage in a locked room that only opens into the office of the IT director, which is also locked when he is not present. The GTEC building that houses this server has several security measures. The server has ample storage space and will be available to the project at no cost.

Expected impact of the PhD outcomes with respect to their business line –	The foreseen collaboration between EIT Digital, GTEC, and University of Trento will lead to a unique knowledge exchange in the areas of innovative brain-computer interfaces, stroke rehab technologies and business developments. The collaboration will strengthen the European and world-wide high-tech position of GTEC. The expected outcomes of this PhD project will give the company a first-mover advantage, that is GTEC will be the first to enter the market with such technologies. This will allow the company to gain a competitive advantage and technological leadership, as well as acquire superior brand recognition and customer loyalty. The solution of the technical challenges faced during the PhD will lead to the ideation and realization of new services for various stakeholders, which will greatly increase the company portfolio of products. Bringing the expected new innovations to the market is expected to create new employment at GTEC, and possibly also at other European companies with which it has established relationships. BCIs and the intelligent applications based on them are expected to have very high growth in coming years. GTEC can leverage the PhD project results by attracting new partners and customers, potentially creating a spin-off company in Trento and hiring new employees in this growing market. To help the consortium consider its options after project completion, and train the PhD student in business skills, the PhD thesis will include a Business Plan that addresses post-project commercial options. The PhD student will explore other revenue options such as IP licensing, franchising, providing services (such as in-home setup, training, configuration and monitoring) and strategic partnerships. We will also consider new applications for new groups beyond those mentioned above: adaptive VR and haptic feedback might be developed into new tools for neuromarketing, improved training for athletes or other users, "patient-centred" psychiatry or other therapies for people with autism, stress disorders, depression, ADHD or other very broad conditions. Dr. Guger does have a successful history exploring revenue options other than sales. For example, GTEC's RecoveriX system was introduced in 2016 as a product for sale to help persons with stroke. Since then, GTEC has opened several training gymnasiums where certified therapists provide training with RecoveriX. This service-based EEG approach is still new today. In addition to the RecoveriX-Gyms that GTEC owns, GTEC has also franchised its gyms. About 30 RecoveriX-Gyms are now operational (For a list of locations, please see https://www.recoverix.at/Get-a-Treatment).

PhD thesis time-line and milestones

Deadlines/milestones	Accurate review of state-of-the-art techniques for EEG emotion adaptation; formulation of a proposal of the most promising approaches to improve state-of-the art, including requirements specifications.
	Delivery of an initial prototype that can be used for demonstration and data collection with healthy persons. Phase I testing begins in M13.
	Report on project progress to date, including planned and completed dissemination activities.

	Delivery of an advanced prototype that can be used for demonstration and data collection with healthy persons. Report on Phase I data testing. Phase II testing begins in M25.
	Second internship period at industrial partner concluded. Submission of a paper in a top-tier Open Access journal. Beginning of the thesis writing.
	Delivery of a final prototype that can be used for data collection with healthy persons (after project completion) and a software system for sale (6 months after project completion). PhD thesis finalisation. Submission of a second paper in a top-tier Open Access journal. Final Project Report including data collection, analysis and dissemination across all phases.

International mobility plan. (Possible countries/ institutions to attend and or work from)	**Academic settings:**
	• University of Twente (Twente, NL)
	• University of Barcelona (Barcelona, ES)
	• University of Palermo (Palermo, IT)
	• Technical University of Iasi (Iasi, RO)
	• University of Talinn (Talinn, EE)
	
	Industrial settings:
	• Artinis Medical Systems (Elst, NL)
	  ○ Industrial partner in Eurostars project – produces fNIRS systems. PhD could learn about a non-invasive approach that complements EEG.
	• Virtual Bodyworks (Barcelona, ES)
	  ○ Industrial partner in different projects. The PhD student could learn advanced immersion and "presence" from a top expert in VR (Prof. Mel Slater).

Will the PhD Student do the Business Development Experience at Industrial Partner premises?	Yes. The PhD student will participate in GTEC's internal training courses that address business issues including IP, entrepreneurship, product development cycles, marketing, distribution, cost and pricing, legal and ethical issues, project management and funding sources. The PhD student will also attend business-related meetings for this project and related projects to see different examples of business development with different projects. The PhD student will also observe the RecoveriX-Gym during business hours and other times. The PhD student will interact with therapists, other staff and patients involved in a service-oriented business to provide rehabilitation therapy. This exposure will help the student consider future business options, and Dr. Guger will also provide direct mentoring about RecoveriX-Gym operations.

Apply for this position	If you are interested in applying, you can send an e-mail to doctoralschool@eitdigital.eu, including a CV, a motivation letter, and documents showing your academic track records. Please apply before 15 August 2020.


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