ASME Bio-Systems & Healthcare Technical Committee
SETTING THE STANDARD

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Robotics for Rehabilitation and Training

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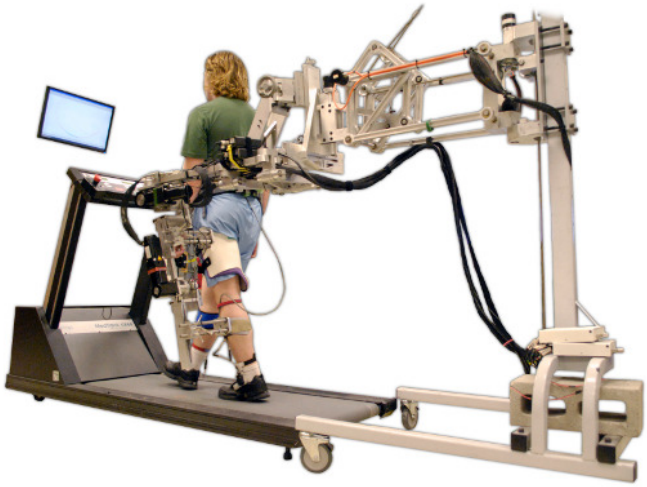
Active Leg Exoskeleton – ALEX II

With over 700,000 new strokes each year, and millions of survivors still dealing with lingering aftereffects, such as reduced mobility and balance, stroke rehabilitation is an urgent need of our society. ALEX II, an active leg exoskeleton is designed specifically for stroke rehabilitation. The exoskeleton moves a stroke patient's paretic leg through a predefined gait pattern, and gently corrects deviations from a desired preset path, chosen based on data of age and size matched healthy individuals. This takes advantage of the brain's neuroplasticity, encouraging patients to unlearn their compensation strategies, which often carry long term negative effects. The exoskeleton has potential in non-rehabilitation applications, such as human skills augmentation, virtual reality training, and others.



Active Leg Exoskeleton ALEX II [1]

Babies Driving Robots

Mobility is an integral part of the exploration process a developing toddler undergoes. As babies navigate through their environment, they learn skills critical to further growth and development. Toddlers dealing with reduced mobility, as a consequence of diseases such as cerebral palsy, spina-bifida, or congenital conditions, lack this opportunity. However, a mobile robot, with an appropriate control interface can be considered as an extension of the child and enable independent world exploration. A haptic force field guidance algorithm encourages the toddlers to direct the robot's control joystick in specific directions. The use of haptic cues greatly speeds up learning, and enables the toddlers to master even challenging navigational tasks. In an improvement on previous work, toddlers interacting with the force field guidance quickly mastered the intricate task of navigating through a cluttered environment. These skills are retained at least a week following the initial training sessions.

Dr. Sunil Agrawal is currently a Professor in the Department of Mechanical Engineering at Columbia University. Dr. Agrawal obtained his PhD degree in Mechanical Engineering from Stanford University in 1990 with emphasis on robotics, dynamics, and control. He currently directs the Robotics and Rehabilitation Laboratory (ROAR) and Robotic Systems Engineering Laboratory (ROSE), which have an active group of graduate, undergraduate, and post-doctoral researchers.

Dr. Agrawal's current and past research has been funded by NSF and NIH, and has focused on the design of intelligent machines using non-linear system theoretic principles, computational algorithms for planning and optimization, design of novel rehabilitation machines, and training algorithms for functional rehabilitation of neural impaired adults and children. Dr. Agrawal's research has resulted in several professional honors that include an NSF Presidential Faculty Fellowship from the White House in 1994, a Bessel Prize from Alexander von Humboldt Foundation in 2002, a Fellow of the ASME in 2004, a Humboldt U.S. Senior Scientist Award in 2007, and a Fellow of American Institute of Medical and Biological Engineering in 2016.

Dr. Agrawal has graduated 22 PhD students and has an active group of PhD students working with him. His research has resulted in close to 400 refereed journal and conference papers, 13 US patents, and 5 pending patent applications. Dr. Agrawal served as the Chair of ASME Design Division in 2014. He served as the Chair of ASME Mechanisms Technical Committee in 2006 and Chair of ASME Mechanisms and Robotics Conference in 2005. He serves on editorial boards and program committees of ASME and IEEE sponsored journals and conferences focused on robotics, control, and rehabilitation engineering.

A baby driving using a haptic joystick interface [2].

Cable Driven Arm Exoskeleton - CAREX

Robotic rehabilitation is becoming ever more prevalent, with exoskeletons leading the way. In upper limb rehabilitation, the standard approach is to use an exoskeleton consisting of mechanical joints, actuated by motors. CAREX, a cable driven arm exoskeleton, is a novel idea where the links are replaced by cuffs and actuators by cables controlled under tension. This lowers the weight of the system by nearly 20 times. The lowered weight of the system enables increasingly dexterous and agile movements – especially in users dealing with limb weakness. A central challenge of cable driven exoskeletons is maintaining tension in the all of the cables during operation, requiring patient specific cable configurations.

Cable driven arm exoskeleton, CAREX [3].

References

1. Srivastava, S., Kao, P., Kim, S.H., Stegall, P., Zanotto D., Higginson, J., Agrawal, S. K., Scholz, J. P., "Assist-as-needed Robot-aided Gait Training Improves Walking Function in Individuals Following Stroke", *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, Vol. 23, No. 6, 2015, 956-963.
2. Chen, X., Ragonesi, C,, Galloway, J. C., and Agrawal, S. K., "Training Toddlers Seated on Mobile Robots to Drive Indoors among Obstacles", *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, Vol. 19, No. 3, 2011, 271-279,
3. Mao, Y., Jin, X., Dutta, G., and Agrawal, S. K., "Human Movement Training with a Cable-driven Arm Exoskeleton (CAREX)", *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, Vol. 23, No. 1, 2015, 73-83.

BSHC News

Dr. David Hoelzle (University of Notre Dame) has received an NSF CAREER award for his project titled "*Manufacturing Tools for the Next Generation of Tissue Engineering, Manufacturing Education for the Next Generation of Engineers*"
https://www.nsf.gov/awardsearch/showAward?AWD_ID=1552358

Dr. Davide Piovesan, Director of the Biomedical Engineering Program at Gannon University, has been awarded the Cooney-Jackman Endowed Professoships from August, 2016 through 2017-18 academic years ($75,000). The title of the grant is "*The effect of water buoyancy on patient movement initiation*." The main objective of the grant is the construction of an underwater motion tracking system to understand and characterize the recovery process of stroke survivors during aquatic-therapy.

Ramin Bighamian (PhD Candidate/Advisor: Jin-Oh Hahn; University of Maryland, College Park) was selected one of 5 Finalists for the DSCC Best Student Paper Award at ASME Dynamic Systems and Control Conference (DSCC 2015) for the paper entitled "A Control-Oriented Model of Blood Volume Response to Hemorrhage and Fluid Resuscitation".

Ramin Bighamian (PhD Candidate/Advisor: Jin-Oh Hahn) was selected as Future Faculty Fellow of the A. J. Clark School of Engineering at the University of Maryland, College Park.

BSHC Publications

1) Ali Utku Pehlivan, Dylan Losey, and Marcia K. O'Malley, (2016) Minimal Assist-as-Needed (mAAN) Controller for Upper Limb Robotic Rehabilitation, *IEEE Transactions on Robotics*, 32(1):113-124, doi: 10.1109/TRO.2015.2503726\

2) Priyanshu Agarwal, Jonas Fox, Youngmok Yun, Marcia K. O'Malley, and Ashish D. Deshpande (2015) An Index finger exoskeleton with series elastic actuation for rehabilitation: Design, control and performance characterization, *International Journal of Robotics Research* (IJRR), 34: 1747-1772 doi: 10.1177/0278364915598388

3) J.D. Brown, A. Paek, M. Syed, M.K. O'Malley, P.A. Shewokis, J.L. Contreras-Vidal, R.B. Gillespie, and A.J. Davis (2015) An exploration of grip force regulation with a low-impedance myoelectric prosthesis featuring referred haptic feedback, *Journal of Neural Engineering and Rehabilitation*, 12(104): doi: 10.1186/s12984-015-0098-1

4) Cassidy Duran, Sean Estrada, Marcia O'Malley, Malachi Sheahan, Murray Shames, Jason T Lee, and Jean Bismuth (2015) The model for Fundamentals of Endovascular Surgery (FEVS) successfully defines the competent endovascular surgeon, *Journal of Vascular Surgery*, 62(6):1660-1666e.3

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5) Segura M., Coronado L.E. Maya M., Cardenas A. and Piovesan. D., Analysis of recoverable falls via Microsoft Kinect: Identification of third-order ankle dynamics, *Journal of Dynamic Systems Measurement And Control,* Special issue on Biomedical Sensing, Dynamics, and Control for Diagnostics, Treatment, and Rehabilitation, doi:10.1115/1.4032878

6) Piovesan D., Zaccariotto M., Bettanini C., Pertile M., Debei S., Design and Validation of a Carbon-Fiber Collapsible Hinge For Space Applications: a Deployable Boom, *ASME Journal of Mechanisms and Robotics*, doi:10.1115/1.4032271

7) Torab P., Piovesan D., Vibrations of Fractal Structures: On the Non-Linearities of Damping by Branching. *ASME Journal of Nanotechnology in Engineering and Medicine*, special issue on Fractal Engineering and Biomedicine, doi:10.1115/1.4032224

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8) Narciso, C., Cowdrick, K. R., Zellmer, V., Brito-Robinson, T., Brodskiy, P., Hoelzle, D. J., … Zartman, J. J. (2016). On-chip three-dimensional tissue histology for microbiopsies. *Biomicrofluidics*, 10(021101). doi: 10.1063/1.4941708

9) Xie, Y., Rustom, L. E., McDermott, A. M., Boerckel, J. D., Johnson, A. J. W., Alleyne, A. G., & Hoelzle, D. J. (2016). Net shape fabrication of calcium phosphate scaffolds with multiple material domains. *Biofabrication*, 8(1), 015005. doi: 10.1088/1758-5090/8/1/015005

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10) C.S. Kim, J.M. Ansermino, J.O. Hahn, "A Comparative Data-Based Modeling Study on Respiratory Gas Exchange," *Frontiers in Bioengineering and Biotechnology*, Vol. 4, No. 8 (doi: 10.3389/fbioe.2016.00008).

11) R. Bighamian, S. Solemani, A.T. Reisner, I. Seri, J.O. Hahn, "Prediction of Hemodynamic Response to Epinephrine via Model-Based System Identification," *IEEE Journal of Biomedical and Health Informatics*, Vol. 20, No. 1, pp. 416-423, 2016.

12) C.S. Kim, A.M. Carek, R. Mukkamala, O.T. Inan, J.O. Hahn, "Ballistocardiogram as Proximal Timing Reference for Pulse Transit Time Measurement: Potential for Cuffless Blood Pressure Monitoring," *IEEE Transactions on Biomedical Engineering*, Vol. 62, No. 11, pp. 2657-2664, November 2015 [Editor's Choice Article in Science Translational Medicine].

Graduates

Joshua Mehling (Advisor: Marcia K. O'Malley; Rice University) completed his PhD degree in Mechanical Engineering in December 2015. The title of his dissertation was "*Impedance Control Approaches for Series Elastic Actuators*". He is currently Technical Discipline Lead - Robotic Controls at NASA Johnson Space Center.