FACILITIES AND EQUIPMENT AVAILABLE TO THE BRAIN REU SITE

The following Facilities and Equipment are available from the Industry-University Cooperative Research Centers (IUCRC) for Building Reliable Advances and Innovations in Neurotechnologies (IUCRC BRAIN) – a nationally-ranked center funded in part by the National Science Foundation and Industry. Please note that the facilities and equipment are listed for all BRAIN faculty mentors; for lack of space, only a subset of these faculty mentors are listed in the Project Description.

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A. IUCRC BRAIN FACILITIES AND OTHER RESOURCES

University of Houston/ Overall Scientific Environment

The University of Houston (UH) is the leading public research university in the city of Houston, the nation's fourth largest city and energy capital of the world. It is a member of the Texas Medical Center (TMC) – the largest medical center in the world. Founded in 1927, UH is now the third largest university in Texas with 4,000+ faculty and staff and 40,914 undergraduate and graduate students in more than 300 undergraduate and graduate academic programs. The University's distinguished faculty members include a Nobel Peace Prize laureate, Tony Award winners and 18 members of the National Academies of Science and Engineering. UH is also the second most ethnically diverse major research university in the United States with students coming from over 137 nations, drawn by the University's outstanding academic programs, exceptional research opportunities and extraordinary diversity. UH enrolls more than 11,000 students in 97 health-related degree programs and conferring nearly a quarter of health degrees in the region. UH is classified by the Carnegie Foundation as a R1 – highest research activity – institution and is one of only three Tier One public research universities in the nation with a Hispanic-Serving Institution (HSI) designation. It is the only such institution in Texas, being among the top 100 colleges and universities conferring degrees to Hispanic students. It is also recognized as an Asian American Native American Pacific Islander Serving Institution (AANAPISI). US News & World Report ranks UH as the 2nd most ethnically diverse campus. UH embraces diversity as a driving force instrumental to its institutional success and fosters an open, welcoming environment where students, faculty and staff of all backgrounds can learn, work and serve together. UH Health represents one of UH's top Strategic Initiatives, which has led to significant investments in UH's Third Ward Initiative, a collaboration with Houston's historic Black community to transform its schools, businesses, and healthcare resources. Additionally, UH recently completed the construction of the Health–2 building with space dedicated to affordable, integrative (physical and mental) health service provision to our underserved communities. Finally, UH established the Helping Everyone Achieve a LifeTime of Health (HEALTH) Research Institute in September 2016 to serve as the university's hub for novel health research.

Summary of Center Facilities. Figure 1 provides a comprehensive listing of the facilities available. Twelve research areas – Big Data, Neuromodulation, Neuro rehabilitation and Assistive Devices, Neural Activity Measurement, Clinical Trials, Device Development, Device Interoperability, Regulatory Science, Neurotechnologies for Sports, Neurotechnologies for Smart Factories, Neurotechnologies for Art, Ethical T- are represented. All of these facilities are well supplied with equipment appropriate for neurotechnology research, and many have embedded technical, communications, and administrative support.

UH: University of Houston, ASU: Arizona State University, UMH: University Miguel Hernandez, TEC: Tec Monterrey

Figure 1 BRAIN Research facilities. Note: Some laboratories have contributions to multiple thrust areas.

1.1 IUCRC BRAIN at the University of Houston Site

1.1.1. The BRAIN CENTER- Welcome Center

Overview: The BRAIN Welcome center is located on the third floor, room N301 of the Engineering Building 1 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately 417 square feet of space. The office space, designated to welcome faculty, students, members and visitors, contains business meeting facilities, and office space for the Center Program Manager with computer, internet, telephone and multimedia facilities. Neurotechnologies are also showcased in the Welcome Center.

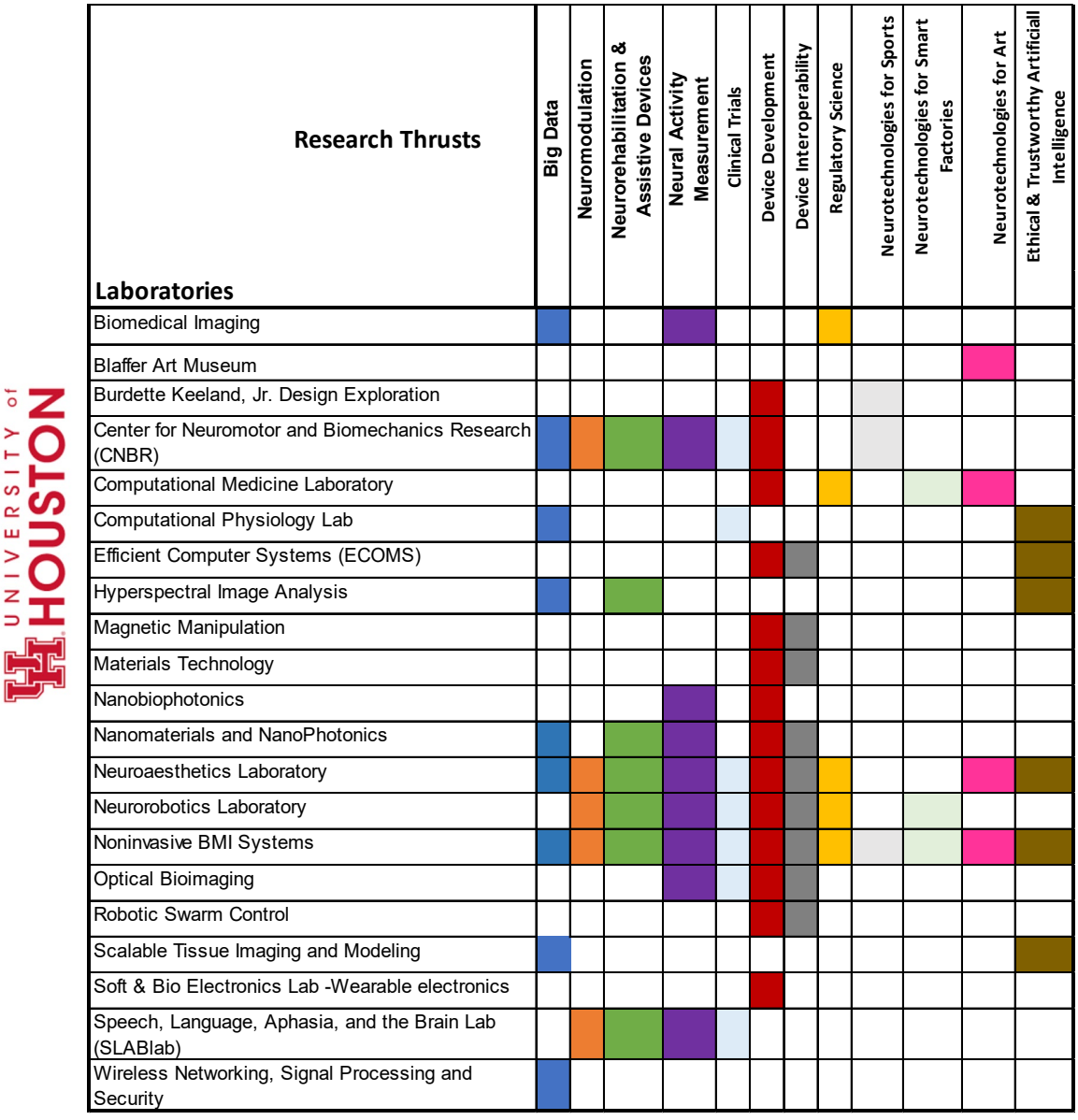

Figure 2 facilities at University of Houston

1.1.2. **Biomedical Imaging Lab -** (Lab Director George Zouridakis)

Overview: Biomedical Imaging Lab is located on the #T1-117 room of the Technology Annex Building in the College of Technology at the University of Houston main campus and encompasses approximately 2000 square feet of laboratory space. Dr. Zouridakis is the PI and leader of the University of Houston team that received an NSF Major Research Instrumentation Award (CNS-0521527) to build research infrastructure for large-scale integration of biomedical data.

The lab has the following specialized capabilities:

Equipment:

- High-resolution functional brain imaging system (ActiveTwo, BioSemi, The Netherlands) that provides 256 channels of neurophysiological recordings, with active sensors (electrodes with built-in bioamplifiers for noise cancellation), and it was the first system of its kind available in the United States.
- Near Infrared Spectroscopy for functional brain imaging using 64 channels of laser diodes (Imagent, ISS), one of very few existing systems worldwide.
- Wireless 12 channel EEG system (CleveMed), leads and transmitter connected to belt; for monitoring brain activity and ECG.
- Wireless 14 channel EEG system (Emotiv), headphones-type device totally wireless for monitoring brain activity.
- The lab is equipped with nine workstations that control the generation and delivery of visual and auditory stimuli, data acquisition, and data analysis and fusion with MRI and CT images. All computers are connected via Gigabit fiber optic to local networks and to the Internet for fast data exchange with various collaborating labs. All computers are equipped with powerful software for algorithm development. In particular, for image processing we use MATLAB.

New computational resources:

- 90 core Beowulf cluster with two file server nodes, totaling 24 TB disk space and SunFire x4200 servers
- a shared memory system composed of:
  - 4 AMD Opteron 880 dualcore processors for a total of 8 cores per server
  - each having 32 GB RAM
  - 300 GB disk space
  - DVD and floppy drives
  - all attached via fiber to disk storage with a capacity of 2 TB.

The facility also includes a Visualization Wall and accessories

- Namely 16 (4x4 matrix) 21" LCD displays
- Four driver workstations (Sun Ultra40): each with two, dualcore AMD Opteron 2.4 GHz processors for a total of 4 cores, 8 GB RAM; 250 GB disk space; 2 NVIDIA Quadro FX 4500 network interface cards.

Computing Resources: Among the unique resources available in my lab is a private queue on a fast cluster, Maxwell, which is run by the University of Houston High

Performance Computing Center and features 5,250 CPUs, a multitude of software packages for parallel scientific computation in a variety of programming languages, specialized libraries for code optimization, statistical data analysis, and data visualization.

Storage Resources: The distributed storage network provides 76TB of disk distributed over 16 storage servers. These servers are located with TLC2, IMD, Geosciences, and Biology/Biochemistry. There is a dedicated fiber network on campus connecting these storage servers and the computing resources at TLC2 and the Research Computing Center. There are also 3 Alcatel switches, each with 24 ports that can possibly be used in the Beowulf cluster for internal message passing among the compute nodes. Currently, for this purpose, the system uses a 96 port Cisco switch.

1.1.3. Blaffer Art Museum

Overview: The Blaffer Art Museum is located in the Fine Arts Building in the Kathrine G. McGovern College of Arts at the University of Houston main campus. The Blaffer Art Museum has served to conduct studies to collect neural data from thousands of people while engage in creative activities (dancing, playing music, making art, or viewing it; Figure 3). A $2.25-million dollar renovation designed by New-York based Work Architecture Company, which marks the most significant and transformative facility improvement in the museum's 39-year history. It greatly enhanced the visitor experience with the addition of a street-side facade and entrance, a courtyard cafe, and dedicated spaces for public and education programs, which has allowed Blaffer to significantly increase the quantity and quality of programs presented in conjunction with exhibitions. Blaffer serves an immediate audience of 40,000 students and 4,000 faculty/staff at the University of Houston, and 4.1 million people in the city of Houston and surrounding Harris County. One of the most culturally diverse campuses in one of the nation's most culturally diverse cities, Blaffer's annual attendance of 15,000 mirrors surrounding demographics: 41% Hispanic, 32% White, 20% Black, and 6% Asian.

Figure 3. The museum as a research laboratory. Exhibitions at the Blaffer Art Museum at the University of Houston have served to both conduct human subjects research on neuroaesthetics to understand the brain response to the arts, and for STEAM Outreach

1.1.4. Burdette Keeland, Jr. Design Exploration Lab (Lab Director: Jeff Feng)

Overview: The Burdette Keeland, Jr. Design Exploration Lab is located at College of Architecture and Design at the University of Houston main campus and encompasses approximately 8,500 square feet of laboratory space. With over 50 total machines, the lab spaces are well equipped with the latest in woodworking, metalworking, and digital fabrication tools. Students who have attended safety orientations and instructional demonstrations have convenient access to important tools of their professions, providing them valuable experience in prototyping, fabrication, and model building as they compete in their discipline.

The Materials Research Collaborative (MRC) at the University of Houston College of Architecture and Design serves as a materials resource for material discovery, innovation,

instruction, and research. On- going work of the MRC includes uncovering new and innovative materials, cataloging the physical samples, and researching and inputting data regarding the specific extrinsic and intrinsic properties of these materials. The MRC is also engaged in specific material research projects such as a database of local materials, LEED v 4 consulting, and carbon emissions analysis of buildings.

The Architecture and Design Computer Lab offers a variety of programs on the windows platform allowing students to create drawings, BIM models, parametric models, and solid models. There are over 40 computers, an 11x17 scanner, a large format scanner, 2 printers, and 6 plotters to allow students to conceptualize and realize their creative designs.

- **Programs Currently Installed:**
  - Adobe Creative Suite ArchiCAD
  - AutoCAD Building Design Suite KeyShot
  - Microsoft Office
  - Rhino with Grasshopper and V-Ray Solidworks
  - Vectorworks

1.1.5. Center for Neuromotor and Biomechanics Research – (Directors: Charles Layne, Stacey Gorniak, Pranav Parikh, Lee Beom-Cham, Adam Thrasher)

Overview: The University of Houston Center for Neuromotor and Biomechanics Research (CNBR) was established by the UH Vice President for Research on April 16, 2009. Led by faculty from the Department of Health & Human Performance (HHP), this laboratory was created to provide a focal point for multidisciplinary studies of human movement control. By bringing together scientists, engineers, and clinicians interested in studying basic physiological mechanisms, functional characteristics of individuals and populations, and rehabilitation techniques, CNBR was conceived to fill a vacant niche in the Houston area as a singular laboratory for understanding performance of various normal, abnormal, and elite populations, as well as to improve the quality of life for those disabled by the effects of injury, disease, or aging.

The Center is located in the John P. McGovern Campus of Texas Medical Center at 2450 Holcombe Boulevard. The CNBR facility comprises 2770 ft^2 of leased laboratory space that accommodates three faculty offices, six graduate student carrels, a conference area, and a broad reconfigurable experiment space. Each office is equipped with a computer, network connection, telephone service and access to local printers.(Figure 4)

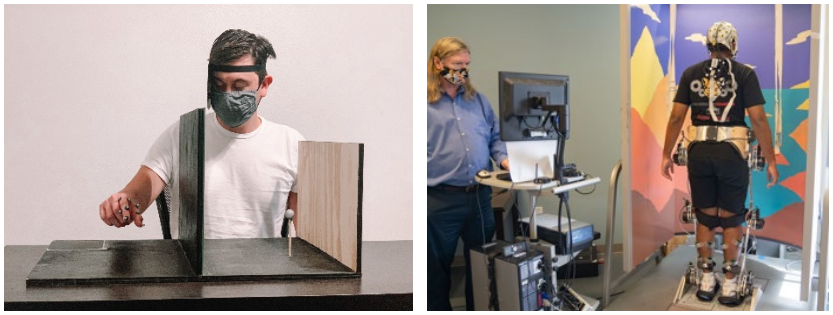

Figure 4

Equipment: Specialized research equipment housed in the Center includes:

- 13 Laptop Computers
- a 16 Camera 3D video motion capture and analysis system (Vicon, Oxford, UK)
- a Multi-channel 3D inertial motion tracking unit system (MTx, Xsens Technologies, Enschede, The Netherlands)
- a Multi-channel wireless EMG (Electromyography) and IMU (Inertial Measurement Unit) system (TrignoM IM, Delsys Inc, Boston, MA)
- a Low-amplitude tri-axial accelerometer (ACL-300-10G, Biometrics Ltd., Newport, UK)
- a Digital pinch-dynamometer (P200, Biometrics Ltd., Newport, UK)
- a Digital grip-dynamometer (G200, Biometrics Ltd., Newport, UK)
- 4 DataLOG wireless data acquisition devices (DataLOG, Biometrics Ltd., Newport, UK)
- Biometrics BNC synchronization cables (SYNC1BNC, Biometrics Ltd., Newport, UK)
- a Biometrics DataLINK system (Biometrics Ltd., Newport, UK)
- a Multi-channel wireless EMG and electronic goniometry suite (Biometrics Ltd., Gwent, UK)
- a Standard 8-channel BTS FREE EMG system (BTS Engineering, Brooklyn NY)
- 2 Standard 8-channel EMG suites (Bagnoli-8, Delsys Inc, Boston, MA)
- a Standard 16-channel EMG suites (Bagnoli-16, Delsys Inc, Boston, MA)
- Standard dEMG sensors (Delsys Inc, Boston, MA)
- a Delsys Myometer III (Delsys Inc, Boston, MA)
- 2 Transcranial magnetic stimulation devices (Magstim Super Rapid^2 and Magstim BiStim^2, Magstim Company, Whitland, Wales, UK)
- 2 70-mm diameter figure-eight TMS coils (Jali Medical / Magstim, Whitland, Wales, UK)
- 2 Custom made 50-mm diameter figure-eight TMS coils (Jali Medical / Magstim, Whitland, Wales, UK),
- a TMS chair (all by Magstim Company Limited, Carmarthenshire, UK)
- a Brainsight TMS Navigation for MRI based TMS Neuronavigation (Rogue Resolutions, Cardiff, UK)
- a 16-channel CED Micro1401 data acquisition systems (Cambridge Electronic Design Limited, Cambridge, England)
- a Transcranial Direct Current Stimulation device (HD-tDCS) and associated HD-Explore software (Soterix Medical, New York, NY)
- an Electrical pulse stimulus generator system (Model S88, Grass, West Warwick, RI) with stimulus isolation unit (Model SIU5, Grass, West Warwick, RI)
- a Functional electrical stimulation cycle (RT-300, Restorative Therapies Inc., Baltimore, MD)
    - a Standard electronic treadmill (Biodex RTM 400)
- a Fully-instrumented dual belt treadmill (Bertec Corp, Columbus, OH),
- a Custom-built full body offloading suspension rig, an AlterG Anti- gravity M/F320 unloading treadmill – (AlterG, Fremont, CA)
- a Gaitrite portable walkway system (CIR Systems, Havertown, PA)
- a Computerized dynamic posturography system (Balance Manager, NeuroCom Int'l, Clackamas, OR),
- 3 Large ground mounted multi-axis force platforms (AMTI, Watertown, MA)
- 4 Large flat screen digital display units (Samsung, Sharp)

- an In-shoe pressure mapping systems (Tekscan F-Scan, Tekscan, Inc., Boston, MA)
- a Psychomotor reaction and movement time panel (Moart Model 35601, Lafayette Instruments, Lafayette, IN)
- a Virtual reality software system (WorldViz, Santa Barbara, CA)
- an Immersive virtual reality training and rehabilitation system (IREX, GestureTek Health, Toronto, Ontario)
- 8 Miniaturized multi-axis force/torque transducers (Nano-25 SI-125-3, ATI Industrial Automation, Apex, NC)
- a Multi-joint torque-velocity dynamometer (Biodex 3, Biodex Medical Systems, Shirley, NY)
- 6 C2 tactors and one controller (Engineering Acoustics Inc., Casselberry, FL)
- 2 Custom made Motorized Ankle Dorsiflexion Stretchers (prototypes, S. Korea)
- a TrueOne 2400 Metabolic Measurement System (ParvoMedics, Sandy, Utah)
- a Lactate Plus Meter (Nova Biomedical, Waltham, MA), 2 Polar RCX3 Heart Rate Monitors (Polar, Kempele, Finland)
- 2 Sets of 25 Pearl Markers (15.9mm, B&L Engineering, Santa Ana, California), 5 VB115 Techno Concept Tendon Vibrator Kits (Techno Concept, France)
- 3 Semmes- Weinstein Monofilament Testing Kit (Touch Test Sensory Evaluators; Stoelting, Co. Wood Dale, IL)
- 3 Omron Wrist Blood Pressure Monitors (BP652, Omron, Japan)
- a CardioCheck PA Analyzer (PTS Diagnostics, Indianapolis, IN)
- 2 Grooved Pegboards (Lafayette Instrument, Lafayette, IN)
- a Purdue Pegboard (Lafayette Instrument, Lafayette, IN)
- a Jebsen Taylor Hand Function Test (North Coast Medical, Gilroy, CA)
- a Functional Dexterity Test (North Coast Medical, Gilroy, CA)
- a Wii fit game system (Nintendo, Redmond, VA)
- a JVC GR-DV2000 digital video camera (JVC, Long Beach, CA), a DELL M210X digital projector (DELL), a Monarch PLT200 Laser Tachometer (Monarch Instrument, Amherst, NH),
- a Tektronix
- TDS 2002B digital oscilloscope (Tektronix, Beaverton, OR)
- a Tektronix AFG 3021B function generator (Tektronix, Beaverton, OR)
- a Detecto Mass Scale, a Health-o-meter Pro digital mass scale
- 11 expandable/ collapsible tripods,
- 2 E-prime Serial Response Boxes (Psychology Software Tools, Inc., Sharpsburg, PA)
- a Full anthropometric suite, and a number of National Instrument Data Acquisition devices (NI DAQ, Austin, TX).

1.1.6. **Computational Medicine Laboratory at the University of Houston** (Lab Director: Rose Faghih)

Overview: CML is located on the third floor of Engineering Building 2 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately 500 square feet of laboratory space (2 rooms). The office space for these laboratory members contains 7 desks for students and researchers. The lab members are each provided desktop computers with access to the University network including access to UH Center for Advanced

Computing and Data Systems (CACDS). Moreover, Dr. Faghih is a member of NSF Industry/University Collaborative BRAIN Research Center, and through this center CML has access partnerships that allow rigorous testing of efficacy, safety and long- term reliability of neuro-technology. Furthermore, CML has unrestricted access to a comprehensive collection of all relevant scientific, engineering, and media publications at the University of Houston Library.

The lab has the following specialized capabilities:

- **MP160 BioPac System:** The BIOPAC MP160 system is a modular data acquisition and analysis system for life sciences research. This 16-channel system comes with its own dedicated software package named AcqKnowledge with specialized signal analysis capabilities. CML has wireless electrocardiogram, electromyogram, electrodermal activity, temperature, photoplethysmogram and respiration sensors compatible with the BIOPAC MP160.

- **BIOPAC MP36 Educational System:** The BIOPAC MP36 is a supplementary four-channel data acquisition system for education and life sciences research. The system has built-in universal amplifiers for recording a wide range of physiological signals, a stimulator, audio output, external trigger and digital I/O lines, and is suitable for a variety of hands-on educational applications. The MP36R System is also capable of airflow and gas (pulmonary function) analysis.

- **BrainVision actiCHamp Electroencephalogram (EEG) System:** The actiCHamp is a dedicated research-grade EEG acquisition system including an amplifier, active electrodes, caps and recording software. CML has two 32-channel EEG headsets to perform experiments involving simultaneously recordings from two subjects.
- **Noldus FaceReader:** The FaceReader is a complete facial expression analysis software package. It automatically analyzes 6 basic facial expressions - neutral, contempt, boredom, interest, and confusion. It also calculates gaze direction, head orientation, personal characteristics and over 20 action units on a face. The Project Analysis Module is ideal for advanced analysis and enables more rapid insight into the effects of different stimuli.
- **MUSE Electroencephalogram (EEG) Wearable Headset:** This EEG sensing wearable headband is intended for easy at-home use.
- **NIRSPORT Functional Near Infrared Spectroscopy (fNIRS) Headsets:** The NIRSport is a research-grade system for acquiring fNIRS from any location on a person's head in any environment. fNIR measurements can be recorded concurrently with any other sensing modality. CML has a system affording the capability to collect 20-channel fNIRS data from two subjects simultaneously.
- **Empatica E4 Wearable Wristband with Physiological Sensors:** The E4 wristband is a wearable research device that offers real-time physiological data acquisition and an accompanying software package for in-depth analysis and visualization. The E4 measures blood volume pulse (photoplethysmogram), electrodermal activity, peripheral skin temperature in addition to 3-axis accelerometer data indicating physical exertion or activity. It also contains an event marker button.
- **Wearable Respiration Sensor - Spire Stone:** The Spire Stone measures breathing by means of the repeated expansion and contraction of the torso. This convenient wearable device permits respiration collection data wirelessly in outdoor and everyday environments.

1.1.7. **Computational Physiology Laboratory** (Lab Director: Ioanis Pavlidis)

Overview: The Computational Physiology Laboratory (CPL) at the University of Houston (UH), which is directed by Dr. Pavlidis, has the necessary computing equipment for carrying out this data intensive research.

Server and Data Infrastructure: The CPL server and data management infrastructure (Table 1.1.7) provide a secure and efficient data environment. The servers are located at the University of Houston's Research Computing Center (http://rcc.uh.edu) and are placed in 2 42U racks. They are all connected to the CPL Gigabyte network, serving as Domain servers, SAN servers, and Web servers.

System	Processor(s)	Memory	Disk	Cores
Dell PowerEdge R7425	2 x AMD EPYC 7251 8-Core Processor	32 GB	107 TB	32
Custom Server	AMD EPYC 7351P 16-Core Processor	64 GB	6 TB	32
Dell PowerEdge R510	2 x Intel(R) Xeon(R) CPU E5530	64 GB	2.8 TB	16

Table 1.1.7. CPL's Clouds infrastructure

- **Computers:** Dr. Pavlidis' laboratory is equipped with 6 Dell PC and 11 Mac workstations that are fully networked to the CPL private network with mass storage and regular back-up. All workstations have access to high-speed Internet connections. CPL also has 8 Mac laptops and several printers. All files are password protected and the network is protected by an up-to-date firewall. Software available through the workstations includes packages necessary for data processing, analysis, visualization, and documentation including Javasript, R, Gephi, Microsoft Office, and Adobe tools.
- **Space:** The CPL laboratory is housed at the new University of Houston's Health and Biomedical Sciences Center and consists of 3,000 ft2 of space.
- **Other:** Dr. Pavlidis receives administrative support through TIMES, having access to an Office Assistant, a Financial Assistant, a Project Manager, and a Proposal Specialist. Dr. Pavlidis'group also has access to a conference room that seats 10 people and has video conferencing capabilities. The University of Houston has excellent library resources both online and offline.

1.1.8. **Efficient Computer Systems (ECOMS) Lab** - (Lab Director Xin Fu)

Overview: Sim-SODA (SOftware Dependability Analysis) is a unified simulation framework for estimating microprocessor reliability in the presence of soft errors. It was developed when Dr. Xin Fu was at IDEAL Lab, ECE Department, University of Florida. The lab develops cross-disciplinary approaches (device, circuit, architecture and application levels) to construct high-performance, low-power, and reliable computer systems.

There are many different resources available at the PI's office and Lab:

- Four FPGA platforms
    - Two Virtex®-7 FPGA VC709 Connectivity Kits

- Two Kintex® UltraScale™ FPGA KCU105 Evaluation Kits

- Mobile GPU platforms
  - Four NVIDIA Jetson TX-1 boards
  - 20w Watts Newpowa High Quality 12v Poly Solar Panel
  - Rigol DS1054Z Digital Oscilloscope 50 Mhz DSO 4 Channels
  - Keithley 2308 battery simulating DC power supply
  - RIGOL DM3058E multimeter that can sample the power data up to 1MHz

- Oculus Rift 2 Virtual Reality headset

- High performance cluster, workstations
  - 2 HP s6500 W/O Fans 4U Chassis
  - 8 HP 1500W Ht Plg Pwr Supply Kit
  - 16 HP s6500 Non-Redundant Fan Kit
  - 2 HP s6500 Chassis Handles Kit
  - 17 HP SL230s Gen8 Lft Half Tray Node
  - 17 HP SL2x0s Gen8 E5-2680v2 FIO Kit
  - 17 HP SL2x0s Gen8 E5-2680v2 Kit
  - 118 HP 16GB 2Rx4 PC3-14900R-13 Kit
  - 17 HP 10GbE 2P 560FLR-SFP+ Adptr FIO Kit
  - 16 HP 1TB 6G SATA 7.2k 3.5in QR MDL HDD
  - 16 HP SL230 LFF QR HDD Cage Kit
  - 2 ProLiant s6500 HW Supp
  - 2 HP s6500 4U Rail Kit
  - 4 HP 8GB 2Rx4 PC3-14900R-13 Kit
  - 10 HP 6TB 6G SAS 7.2K 3.5in SC MDL HDD
  - 2 HP 100GB 6G SATA ME 3.5in SC EM SSD
    - HP 512MB FBWC for P-Series Smart Array
  - HP 2U LFF Easy Install Rail Kit with CMA
  - HP 750W CS HE Power Supply Kit
  - 10 PNvidia Tesla P100 GPU
  - 6 Dell Precision T3610

1.1.9. **Hyperspectral Image Analysis Lab**- (Lab Director Saurabh Prasad)

Overview: Hyperspectral Image Analysis Lab is located on the 3rd floor, room S382 of the Engineering Building 1 in the Cullen College of Engineering at the University of Houston main Campus encompasses approximately 452 square feet of laboratory space.

1.1.10. **Magnetic Manipulation Lab** (Lab Director: Aaron Becker)

Overview: The Magnetic Manipulation Lab is located on the third floor, room N392 of Engineering Building 1 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately 394 square feet of laboratory space, the room have an attached room for student office space. The lab has a Biosafety Level 2 rating (BSL-2): (1) laboratory personnel have specific training in handling pathogenic agents and are directed by scientists with advanced training, (2) access to the laboratory is limited when biomedical work is being conducted, (3) extreme precautions are taken with contaminated sharp items. The lab has both a

Ultimaker-2+ and a Ultimaker 3. These 3D printers are suitable for fast prototyping.

Figure 5.. Highlights from the Magnetic Manipulation Lab: medium-size and small-size magnetic manipulators, a power rack, an UR3 robotic arm, computers, microscope and a liquid nitrogen tank.

The lab possesses two magnetic manipulators that were designed and in-house built:

- **A small-scale manipulator** able to produce a gradient of 8000 mT/m – 200× more gradient than current MRI scanners. It contains 6 electromagnets coils arranged in orthogonal pairs. This setup can control magnetic robot in 3D in a cubed shape workspace having a side length of 50 mm (125 cm3).

- **A medium-scale manipulator** able to produce a gradient of 0.12 mT/m – 3× more gradient than current MRI scanners. Six electromagnets are arranged in orthogonal pairs and can be cooled using liquid nitrogen. This manipulator has 6 open bores. This setup can control magnetic robot in 3D in a spherical workspace having a diameter of 150 mm (1,767 cm3). This workspace is large enough to accommodate a human heart phantom with the main arteries and veins. The laboratory is equipped with all the safety equipment needed to safely work with liquid nitrogen.

- To power these electromagnets, the lab has a **power rack with 12 Kepco power supplies.** Each power supply can deliver a current of 20A under 50V. These supplies can be connected together in series or parallel. When connected in pairs, the power rack can deliver to each electromagnet of a manipulator, a maximum of 40A under 50V or 20A under 100V depending on the configuration.

- The lab is also equipped with a **powerful computer system controlling the power rack**. It is composed of a host computer and real-time National Instrument industrial computer. The industrial computer runs a rea-time version of LabVIEW. It is programmed, monitored and controlled by the host computer.
- The industrial computer is connected to an **NI EtherCat interface**, that allows high speed control of hardware and high-speed reading of sensors.

- The Lab possesses **four Basler cameras (two acA800 and two acA2040)** to perform the visual tracking of magnetic robots. The two acA800 are able to capture

500 fps with a resolution of 500×600 px and the two acA2040 are able to capture 100 fps with a resolution of 1200×800 px. These cameras can be connected via USD on the industrial computer for real-time image processing.

- The Lab possesses all the material needed to study swarms of miniature magnetic robots (microscope, particle image velocimeter, precision welder, etc.), as well as all the basic equipment needed for research in robotics (voltmeters, oscilloscopes, soldering irons).

- The power supplies are equivalent to those used by our SMU collaborators. We have budgeted funds for building a 3D Helmholtz magnetic manipulator that matches the manipulator at SMU (a second Death Star).

- **Glass observation room:** High-end desktop computers for research are at student desks in the glass observation room adjoining the lab

1.1.11. **Materials Technology Lab** (Lab Director: Francisco Robles Hernandez)

Overview: Dr. Robles Facilities are located on the first floor of Technology Buildings 1 and 2 in the College of Technology at the University of Houston main campus and encompasses two laboratory spaces and an approximate surface area of 600 square feet of laboratory space in addition to the metallurgical lab that is another share facility (Dr. Robles is responsible for it) with 400 square foot print. The office space for this laboratory members contains 6 desks for students and researchers. The lab members share 4 desktop computers with access to the University network including access to UH Center for Advanced Computing and Data Systems (CACDS). Furthermore, all lab has unrestricted access to a comprehensive collection of all relevant scientific, engineering, and media publications at the University of Houston Library.

Equipment:

- Raman confocal microscope
- Thermal Analysis
- 2 Sonicators: Misonix 4000
- Fully equipped machine shop with CNC capabilities
- 1 Chemical and biological hoods
- High temperature furnace with control atmosphere capabilities
- Metallographic sample preparation
- Glove box with protective atmosphere capabilities
- Optical microscopy
- Induction furnace
- High intensity pulse laser facility
- High energy mechanical milling (room temperature)
- UV-VIS-IR
- Electrochemical impedance spectroscopy

1.1.12. **Nanobiophotonics Lab** (Lab Director: Wei-Chuan Shih)

Overview: The Wei-Chuan Shih's Lab is located on the fourth floor, room W432 of Engineering Building 2 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately 1000 square feet of laboratory space. The laboratory occupies 4 rooms totaling 600 square feet (250, 150, and 100, 100 sq. ft.). These rooms will be available for the proposed studies. PI has a recently renovated new space on the third floor, room E396 in the Engineering Building 1, with approximately 400 square feet. The laboratory is equipped with 4 optical tables with vibration isolation systems.

The lab has the following specialized capabilities:

- **Inventory:**
  - Basic hardware (lenses, filters, etc)
  - photodetectors
  - optics
  - software tools for training of graduate and undergraduate students

- **Equipment:**
  - **Light sources:**
  - Laser 1 (Titanium:Sapphire tunable CW laser, Newport 3900S): 3W CW output tunable from 700-950nm.
  - Laser 2 (DSPP laser (532 nm), Newport Millennia Pro 10): pumps Laser 1 and can be used as an independent source with 10W CW output.
  - Laser 3 (Titanium:Sapphire tunable ultrafast laser, Newport Tsunami): 1.5W 80 femtosecond pulses at 80 MHz repetition; output tunable from 700-950nm.
  - Laser 4 (DSPP laser (532 nm), Newport Millennia): pumps Laser 3 and can be used as an independent source with 5W CW output.
  - Laser 5 (ultrafast oscillator, MaiTai, Spectra Physics): 100 fs laser pulses at 80 MHz for 3W output. Wavelength tunable 700-1050 nm.
  - Laser 6 (Inspire OPO, Spectra Physics): second generation and optical parametric oscillator, extending the MaiTai wavelength tuning range to 350-2400 nm.

- **Other light sources:**
  - TH, Xenon lamps
  - LEDs for GFP
  - Cy3
  - and various fluorescence imaging, light scattering and plasmonic imaging.

  - **Detectors:**
  - Spectrograph/CCD detector 1 (Princeton Instrument, LS-785/PIXIS 400BR): Records near-IR Raman and fluorescence spectra and images.
  - Spectrograph/CCD detector 2 (Princeton Instrument, Acton SP300i/PIXIS 400): Records both UV/Vis and near-IR Raman and fluorescence spectra and images.
  - Spectrograph/CCD detector 3 (Princeton Instrument, Acton SP300i/PIMAX intensified CCD minimal gate 500 picosecond): Records both UV/Vis and near-IR time-resolved fluorescence spectra and images.
  - Spectrograph/CCD detector 4 (Princeton Instrument, Acton SP300i/ProEM EM CCD at 50 frame per second): Records both UV/Vis and near-IR time-resolved fluorescence spectra and images.
  - InGaAs linear array 1x256 (Hamamatsu): Response from 900 to 2400 nm.

- Laser power meters: Ophir photodiode heads (1W & 3W) and thermal heads.

- **Microscopy:**
  - Inverted microscopes (2x Olympus IX71): This provides the foundation on which our Raman/fluorescence microscope is built. It has built-in phase contrast imaging function.
  - Microscope objectives: Olympus 60XW NA1.2, 100XO NA 1.5, phase contrast, and various others.
  - Galvanometer scanning mirror: These mirrors enable rapid scanning of the line-illumination over an extended area
  - An upright filter-based multi-channel fluorescence microscope.
  - Spatial light modulator 1 (Hamamatsu LCOS-X10468-02).
  - Spatial light modulator 2 (Boulder Nonlinear Systems).
  - Spatial light modulator 3 (Texas Instrument Digital Mirror Devices).
  - Filters: Long-pass, short-pass, band-pass filters are available; Laser filter to clean up, various dichroic filters.

- **Raman probe:**
  - Optical fiber probe for portable Raman spectroscopy from TSI EZRaman.

  - KSV NIMA Langmuir-Blodgett Medium for making nanoparticle monolayer used in the Nanosphere Lithography (NSL).

- **Miscellaneous:**
  - Optical tables x 4 (Newport): This allows vibrational isolation for the entire microscope.
  - Miscellaneous free-space optics and fiber optics: For optical setup.
  - Microscope cell culture stage
  - Microfluidic development environment: A chemical hood will be devoted to microfluidic-specific processes such as PDMS processes, degassing, bonding, etc.

1.1.13. **Nanomaterials and Nanophotinics Lab** - (Lab Director Jiming Bao)

Overview: Nanomaterials and Nanophotinics Lab is located on the 3rd floor, rooms S344 and S344A of Engineering Building 1 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately xx square feet of laboratory space.

Equipment:

- Syntesis Systems:
  - 6750 FREEZER/MILL
  - 8000M Mixer/Mill® High-Energy Ball Mill
  - Chemical Vapor Deposition System
  - Optical Imaging and Spectroscopic Systems
  - Solid State lasers (633 nm, 532nm,473nm, and 337nm)
- Nikon Optical Microscope System

- Home-Built Raman & Photoluminescence System
- Hitachi UV-VIS Spectrophotometer U-2001
- Nicolet Is50 FTIR Spectrometer
- Electrochemical Analytical Systems
- SHIMADZU GC-8AIF Gas Chromatograph
- GOW-MAC Series 350 Gas Chromatograph
- Vacuum System Equipped with Gas Chromatograph
- Vacuum System Equipped with Residual Gas Analyzer
- Accumet AB15 ph Meter
- Closed Cycle Refridgerator System
- Other Tools
- Newport Solar Simulator
- Cascade Microtech Summit 9000 Probe Station
- Newport Solar Simulator
- Home-Built Optical Fiber Drawing System
- Blackbody Radiation Based Optical Fiber Temperature Sensor

1.1.14. **Neuroaesthetics Laboratory** (Lab Director :Jose L. Contreras-Vidal)

Overview: The Neurorobotic laboratory is located on the 4th floor, room E409 of the Engineering Building 2 in the Cullen College of Engineering at the University of Houston main campus, and encompasses approximately 280 square feet of the laboratory space. The lab is comprised of state-of-the-art facility for research and development of noninvasive neurotechnologies for neuroaesthetic and creativity research. (Figure 6)

The lab has the following specialized capabilities:

- Two computer workstations with an array of four 24” displays for computer graphics, 3D modeling and visualization
- EEG-controlled kinetic sculpture that maps EEG patterns to sound, movement and colored lights.
- Media room for creating visual aids, videoclips and other content for STEAM outreach

Figure 6

1.1.15. **Neurorobotics Laboratory** (Lab Director :Jose L. Contreras-Vidal)

Overview: The Neurorobotic laboratory is located on the third floor, room S394 of the Engineering Building 1 in the Cullen College of Engineering at the University of Houston main campus, and encompasses approximately 310 square feet of the main laboratory space. The lab is comprised of state-of-the-art facility for research and development of neurorehabilitation technology such as prosthetics and exoskeletons.

The lab has the following specialized capabilities:

- ***Prosthetics***: Figure 7. A portable bidirectional dexterous robot Smarthand open-platform (Prensilia s.r.l, Italy) with embedded sensorization is available for BMI research. Compliant fingers/thumb are independently driven by electrical motors, by means of tendon transmission. The thumb ab/adduction actuator is placed within the carbon fiber palm, whereas the fingers flexion/extension motors are hosted into a mechanical platform. Tendon tension sensors, current sensors and position sensors are available for bi-directionally interfacing with the robot. The Smarthand hosts an embedded controller and operates through a simple communication interface (RS232).

Figure 7. Hand Neuroprosthesis Controlled by EEG-BCI

- ***One CyberGlove ™*** (Virtual Technologies) for measuring up to 17 joint angles of the hand

- ***Rehabilitation robotics***: One In Motion-2 Robot arm manipulandum is available for stroke rehabilitation studies and a second robot arm is available for upper limb adaptation studies. Based upon the "MIT Manus robot," the InMotion Arm Robot is used to improve elbow and shoulder control in clinical populations with upper limb dysfunction. The benefits of this robot have been shown in multiple research studies involving patients with stroke, cerebral palsy and other neurological conditions.
- ***Lower-Limb powered exoskeleton (NeuroRex, Figure 8)***. A powered lower-limb robotic exoskeleton (RexBionics, New Zealand) augmented with a bran-machine interface is available for people with complete spinal cord injury. This self-balancing powered exoskeleton system is a closed-system.

- **Lower-Body, assists-as-needed powered orthotic system (H2 NeuroExo**). (CSIC), we have developed a powered robotic exoskeleton prototype that can be interfaced with EMG and EEG for automatic gait intention detection from myoelectric and brain signals.

- **Pediatric Lower-Extremity Gait System (P-LEGS).** This powered exoskeleton has an open control architecture and can be interfaced to motion, myoelectric or BMI modules.

- ***Custom functional electrical stimulator (FES):*** A custom eight-channel FES device is available.

Figure 8. Powered Exoskeleton: Rex (RexBionics), H2 (CSIC), and Pediatric Exoskeleton (P-LEGS) (University of Houston).

1.1.16. Noninvasive Brain-Machine Interface (BMI) Systems Laboratory (Lab Director: Jose L. Contreras-Vidal)

Overview: The BMI systems laboratory is located on the fourth floor, room E413 of the Engineering Building 2 in the Cullen College of Engineering at the University of Houston main campus, and encompasses approximately 1432 square feet of the main laboratory space, and 4 sub rooms with roughly 110 square feet each for a grand total of around 1900 square feet. The labs are comprised of state-of-the-art facilities for research and development of noninvasive neurotechnologies and neurorehabilitation technology. The Laboratory has facilities to conduct over-ground and whole-body BMI-robotics experiments, a network of 20 computer workstations for data analysis and software development, two smaller rooms for upper- and lower-limb neurorobotic research, and two offices for postdoctoral associates equipped with computer workstations and teleconference facilities (zoom, skype, TEAMS), available to the project.

The lab has the following specialized capabilities for mobile brain-body imaging (MoBI):

- **Wireless, portable electroencephalography (EEG) devices (Figure 9)**: The laboratory has 7 Brain Products BrainAmpDC Activecap electrode bundles, that can be set as 3 headsets with 64 channels or 7 headsets with 32 channel (description is below), 1 Gel g-tec gel system, 1 Dry Cognionics Quick amp 20, two 8 channel LiveAmp amplifier and data logger, and 26 4-channel Muse headsets.
- The gel-based **Modular BrainAmpDC EEG systems** (Brain Products, Germany) with wireless ActiCap active electrode caps (32 ch and 64 ch) have active impedance check on electrodes and actiShield technology for improved signal-to-noise ratios (SNR) and higher interference rejection, including mechanical motion artifacts that would otherwise be induced by motion of EEG wires. The active electrodes in this system makes it possible to measure scalp potentials with higher electrode impedances, without encountering the noise and interference problems seen in measurements with high-impedance, wired, passive electrodes.

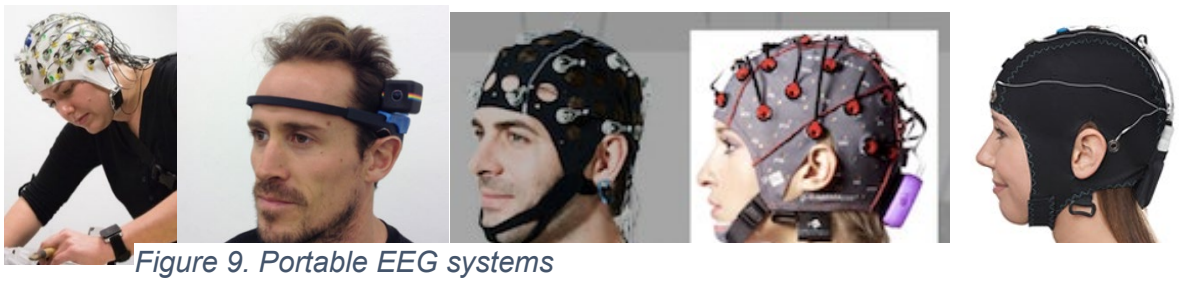

Figure 9. Portable EEG systems

- **Wireless inertial motion sensors and EMG systems**: The laboratory owns inertial motion units (APDM's OPALS) for tracking body movement (see, for example, left most image above showing a woman with an inertial sensor on the left wrist) and wireless EMG electrodes. We have developed a custom software application for multimodal data collection that integrates motion sensing, EMG, EEG, infrared and and video recordings with triggering capabilities.

1.1.17. **Optical BioImaging laboratory** – (Lab Director: Luca Pollonini)

Overview: Optical BioImaging laboratory is located on room # 123 of the Technology Annex Building in the College of Technology at the University of Houston main campus and encompasses approximately 2000 square feet of laboratory and office space allocated to faculty and students, and in which design, assembly and testing of biomedical instrumentation develop in this project will take place.

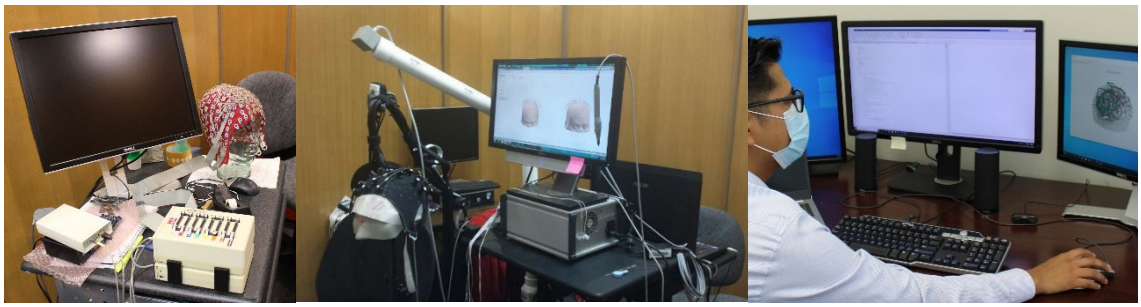

Figure 10

In addition to the lab's space, the College of Technology has a total of 5000 square feet of electronic, mechanical and biotechnology laboratory space that could be accessed at any time. The University of Houston also houses several shared hi-tech facilities and resources such as a nanofabrication facility and a major instrumentation facility regularly accessible by UH faculty and staff. For projects with requirements that go beyond the available resources, PI Pollonini and the College of Technology have developed an extensive network of domestic and international collaborations with companies specialized in fast prototyping, miniaturization and assembly of instrumentation and sensors. The engineering lab is equipped with all optical, optomechanics and electronics tools to develop biomedical devices and instrumentation, including lenses, optical benches, optical mounts, laser drivers, photodetector amplifiers, optical power meters, oscilloscopes, multimeters, soldering stations, and such.

The **Optical BioImaging** lab has the following specialized capabilities:

Equipment:

- Functional near infrared spectroscopy instrument (NIRx Nirscout 16x16; Fig. 10)
- Electroencephalography instrument (Brain Products 64-channels EEG)
- 3D digitizer (Polhemus Patriot),
- Eye tracker (Pupil Labs),
- Virtual reality tool (HTC VIVE),
- Audiovisual stimuli presentation setup (monitor, loudspeakers)
- A suite of software products aimed at operating and synchronizing all these devices.

1.1.18. Robotic Swarm Control Lab (Lab Director: Aaron Becker)

Overview: The Robotic Swarm Control Laboratory (RSCL) is located on the third floor, room N386 of Engineering Building 1 in the Cullen College of Engineering at the University of Houston main campus and encompasses approximately 394 square feet of laboratory space, the room have an attached room for student office space.

The lab is equipped with **rapid prototyping materials** including:

- a MarkForge 3D printer for printing in nylon
- carbon fiber, and Kevlar
- a Versa Laser 3.50 laser cutter
- five Ultimaker 3D printers (three 2+, two 3)
- a pocket NC mill
- an Orion 100c Pulse Arc welder
- a Sherline CNC Mill, a Sherline CNC lathe
- an XY plotter
- electronic and small carpentry tools
- soldering stations, work station computers
- a Ney Vulcan 3-550 laboratory furnace
- three cRIO controllers
- two MyRIO controllers
- oscilloscopes
- microscopes
- and a NI VirtualBench (VB-8012)

- **The lab includes:**
  - a 20'x20'x9' workspace with a 12-camera OptiTrack motion tracking system connected to a glass observation room.
  - A fleet of eight ERA-mobi mobile robots (40cm cube) are equipped for easy configurability and can carry a wide range of equipment.

- **The lab also hosts**:
  - two Solo 3DR drones
  - two heavy-lift multicopters
  - a swarm of Crazyflie quadcopters
  - two OpenROV 2.8 underwater drones

- a BlueROV.

- **Glass observation room:** High-end desktop computers for research are at student desks in the glass observation room adjoining the lab

1.1.19. Scalable Tissue Imaging and Modeling LAB (STIM) (Lab Director: David Mayerich)

Overview: The STIM Lab is located on the third floor, room W309 of Engineering Building 2 in the Cullen College of Engineering at the University of Houston main campus, and encompasses approximately 875 square feet of the main laboratory space. The lab consists of a range of microscopes, imaging systems, and computing resources for cellular-level neuroimaging. The STIM Lab houses resources designed to optimize high-throughput data collection, analysis, and visualization.

The lab has the following specialized capabilities:

- **Workstations:** The STIM Lab is equipped with several highly customizable workstations equipped with high-end nVidia GPUs for CUDA applications. While these systems vary based on user needs, they are generally equipped with:
  - Intel i7 processor
  - X99 (DDR4) chipset
  - 16GB of memory
  - At least one nVidia GTX 970.

- **Network Accessible Storage (NAS):** The STIM Lab maintains a local NAS with 20TB of raw storage to provide a collaborative workspace for large data sets. This is a custom server using the ZFS file system and running FreeNAS. Data acquired using laboratory instrumentation are stored redundantly among several systems using BitTorrent Sync. Individual data sets can be accessed anywhere using a public key available from laboratory personnel (stim@uh.edu).

- **Ultimaker 2 3D Printer:** The STIM lab use an Ultimaker 2 printer to fabricate various components. This printer provides a 20 micrometer layer resolution and a 20 cubic centimeter build volume. Standard ABS and PLA spools can be used. Models must be provided using a micro-SD card in the appropriate format. Most formats are supported by loading the model into CURA and exporting. A microSD-to-USB adapter is available in the lab.

- **Software:** The main research goals is to produce accessible applications for data processing, image analysis, segmentation, and modeling. All of the published software is available via our internal Git server or GitHub. Documentation for most of the lab source code can be produced using Doxygen (a default Doxyfile is provided in the repository).

- **Instrumentation:** The STIM Lab houses several instruments designed for high-throughput imaging and microscopy. The laboratory is optimized for phenotyping large samples, therefore instrumentation is optimized for fast 3D data acquisition (ex. gas PMTs, cooled FPAs).

Thorlabs cerna series laser scanning microscope:

- Wide-field transmission imaging (with polarizer) using a 1.4 megapixel color camera
- Epi-fluorescence imaging using a 1.4 megapixel monochrome camera
- Confocal imaging with laser excitation at 405, 488, 532, and 642nm
- Gas photomultiplier tubes for fast acquisition
- Nikon 16X 0.8NA CFI75 LWD 16xW water immersion with a 3mm working distance.

Nikon eclipse ti-e inverted microscope:

- Wide-field transmission imaging using a 1.4 megapixel color camera
- Mosaic imaging with auto-focus
- Epi-fluorescence imaging using a 1.4 megapixel monochrome camera
- Confocal excitation: 405, 488, 532, and 642nm
- Galvo-galvo laser scanner allows detailed specification of pixel dwell times
- (for fast imaging of large samples, use the Cerna)
- Available optics:
- Nikon PLAN FLUOR 10X 0.3NA with a 16mm WD
- Nikon 60X 1.0NA water immersion with a 2mm WD
- Nikon 100X 1.49NA CFI TIRF oil immersion lens optimized for super-resolution imaging

ASI DISPIM (Dual inverted selective plane illumination microscope)

- 2x Nikon CFI NIR Apo 40X 0.8NA 3.5mm WD objectives for SPIM
- CFI Plan Apochromat 10X 0.45NA 4mm WD objective for inverted microscopy
- 2x 2048x2048 Zyla cameras
- SPIM excitation: 405, 488, 561, 640nm

Openspim light-sheet microscope

  - We've built an easily modified light sheet microscope based on the OpenSPIM design:
- 488nm and 532nm 300mW laser sources
- 2048 x 2048 30-fps ORCA-Flash4.0 LT Digital CMOS camera
- Excitation: Olympus 10X 0.3NA
- Detection: Olympus 20X 0.5NA
- This system is optimized for water immersion, however other objectives can be used for air
- Image stacks can be collected using translation and rotation

Infrared Spectroscopy

- **Agilent cary 620 ftir imaging system**
  - The spectrometer allows fast analysis of homogeneous samples using FTIR:
  - 128x128 liquid nitrogen-cooled MCT focal plane array detector
  - 15X 0.62NA cassegrain objective
  - pixel size: 5.5m (low mag) or 1.1m (high-mag)
  - reflection or transmission mode
  - spectral bandwidth:
  - FPA imaging: 850 to 3900 cm (UDR4) or 850 to 1900 cm (UDR8)
  - Point/mapping: 400 to 4000 cm

- **Daylight solutions mircat quantum cascade laser (QCL)**
    - QCL tunable from 900 to 1800 cm (5.5m to 11m)

- **Data Sets:** Data sets are provided as BitTorrent Sync (Resilio) keys. When possible, we ask that publications using data cite the specified manuscripts to provide details about how the data was acquired. In addition, it is helpful for researchers to keep their downloaded versions of these data sets online, since it increases redundancy and improves the transfer rates of other users.

- **Knife-Edge Scanning Microscopy**
    - Data Set: Whole mouse brain labeled using India ink perfusion
    - Processing: Unprocessed
    - Specifications: voxel size
    - Notes: This data was acquired using Knife-Edge Scanning Microscopy to image sequential coronal sections. The data is raw and appears to be missing a small section of one hemisphere that was outside of the field-of-view of the imaging system during acquisition. This data set is also missing the olfactory bulb, which fell off during brain removal.
    - Sync key: B276WQ4HRKRE7Q5GP4JPBQLGDVFNS7H3X

- **Data Set: Whole mouse brain labeled using India ink perfusion**
    - Processing: Unprocessed
    - Specifications: voxel size
    - Notes: This data was acquired by 3Scan using Knife-Edge Scanning Microscopy to image sequential coronal sections. When using this data, please cite 3Scan (www.3scan.com)
    - Sync key: B5WSUMJLFFXTCYWRWJ5F6RIQZW2OAAQZL

- **Data Set: Whole mouse brain labeled using Golgi-Cox diffusion**
    - Processing: Unprocessed
    - Specifications: voxel size
    - Notes: This data was acquired using Knife-Edge Scanning Microscopy to image sequential horizontal sections.
    - Sync key: BS224SJ4GZ5EKSFVIQYJRFFIUIEANQR5R

- **Mid-Infrared Spectroscopic Imaging**
    - Data Set: SIproc tutorial data set
    - Processing: Unprocessed
    - Specifications: voxel size imaged at cm-1
    - Notes: This data was acquired using a Perkin-Elmer Spotlight FTIR imaging system with a 0.5NA objective. This data set contains 4 cores designed to be used in a tutorial for the SIproc toolkit.
    - Sync key: BKQBA3B5MBL2F4GFADUJYVLYYSUSZ7NOR

    - Data Set: Breast cancer tissue microarray
    - Processing: Unprocessed
    - Specifications: voxel size imaged at cm-1
    - Notes: This data was acquired using a Perkin-Elmer Spotlight FTIR imaging system with a 0.5NA objective by CISL (PI Dr. Rohit Bhargava). This data is a

mosaic of two TMA images from US Biomax (BRC961 and BR1001).
  - Sync key: B53SX67BQ4WXCOBY7NFSI3Y4NWNQYFASC

  - Data Set: Breast cancer tissue microarray
  - Processing: Unprocessed
  - Specifications: voxel size imaged at cm-1
  - Notes: This data was acquired using a Perkin-Elmer Spotlight FTIR imaging system with a 0.5NA objective by CISL (PI Dr. Rohit Bhargava. This data is a mosaic of two TMA images from US Biomax (BR1003 and BR2085b).
- Sync key: BTVLCNSQJY5LM3XSRUCP4OQOXS72WUXE

1.1.20. Soft & Bio Electronics Lab (Lab Director: Cunjiang Yu)

Overview: Dr. Yu in the Mechanical Engineering Department has a comprehensive lab equipped with facilities for micro/nano materials synthesis, conformal stamp printing manufacturing platform, device fabrication, optical imaging, device testing, etc. The group lead by the PI is one of the three groups that co-operate an Energy Device Fabrication Laboratory (EDFL) at UH Energy Research Park, funded by the state of Texas' Emerging Technology Fund (ETF). This 13,000 sq. ft. lab is dedicated for research in flexible electronics and energy devices, with a comprehensive capability of materials processing, device fabrication, metrology and testing, including a broad range of fabrication tools, such as photolithography, thin-film deposition, plasma etching, and the world's first IV and III-V roll-to-roll metalorganic chemical deposition (MOCVD). UH Nanofabrication Facilities which is equipped with an extensive toolset for nano/micro device fabrication and characterization in cleanroom space , will be used by paying user fees. In addition, TcSUH (Texas Center for Superconductivity at the University of Houston) Materials Characterization Facility (MCF) provides service of electron microscopy and microanalysis by paying user fees. Specific equipment to be used in this project in Yu's lab, EDFL, UH Nanofabrication Facilities and TcSUH-MCF is described in the Equipment Section.

- **Materials characterization:**
  - Transmission electron microscope (TEM).
  - Electron back scattered diffraction and focused ion beam (FIB) milling instrument in scanning electron microscope (SEM).
  - Raman spectroscopy.
  - High-resolution X-ray diffraction (Bruker D8 discover).
  - 77-300 K FTIR System with simultaneous transmission/reflectance measurement allowing access to an absorption coefficient in the 0.8-16 microns range.
  - 100-300 K modulated photoreflectance/transmission spectroscopy system.
  - Hall-effect measurement system.
  - Nikon LV150 optical microscope.
  - Nikon D7100 camera for image and movie capturing.
  - Custom made uniaxial mechanical stretchers.
  - Frequency tunable cyclic bending/stretching tester with in situ optical and electrical characterization.
  - Dynamic mechanical analyzer (DMA) (TA Q800, TA Instruments).

- **Device fabrication and characterization:**

- Plasma-enhanced chemical vapor deposition (PECVD) (Plasmatherm 790) for dielectric deposition.
- DC sputter (Edward).
- E-beam evaporator.
- Rapid thermal annealing system (RTT)
- Mask aligners (Karl-Suss MJB3, ABM).
- Spin coater.
- Oxygen plasma asher.
- Probe station.
- IQE measurement system.
- Semiconductor parameter analyzer (Keythley 4200-SCS).
- Chemical fume hoods.
- BHK Mercury line based atomic oxygen reactor.
- Isotemperature oven.
- Vacuum oven.
- Lindberg blue furnaces for solid state doping.
- VAC Omni-Lab dual length glovebox.
- Probe station.
- National Instrument data acquisition system.
- Oscilloscope.
- Potentiostat and galvanostat.

1.1.21. Speech, Language, Aphasia, and the Brain Lab (SLABlab) - (Lab Director Heather Dial)

Overview: The SLABlab is located at Melcher Life Sciences 245D and Garrison Hall 105R and 105S (MEL 245D = ~200 sq ft; GAR 150R and 150S = ~ 160 sq ft each). Equipment and relevant software includes BrainVision BrainProducts Actichamp plus, 64-channel electrode EEG system; BrainVision Analyzer 2.0; E-prime, MATLAB, iMac Pro for HPC, Dell desktop computers for EEG data acquisition and analysis tACS system from Soterix. Other equipment includes etymotic research headphones, headphone buffer, preamplifiers for EEG recordings.

1.1.22. Wireless Networking, Signal Processing and Security (Lab Director: Zhu Han)

Overview: Wireless Networking, Signal Processing and Security lab, founded by the PI in 2008 is located on the third floor, room W319 of Engineering Building 2, and encompasses approximately 650 square feet of space and room S352 of Engineering Building 1 encompasses approximately 190 square feet of space at the University of Houston main campus. Several test beds, including a Software Defined Radio test bed using USRP/USRP2, are under development. Spectrum analyzer from National Instruments is available for validation and spectrum monitoring. Many graduate and undergraduate students are actively involved in several projects in the lab. Currently there are 12 students desks are located in the lab. The teams of undergraduate senior design and REU students are also working in the lab.

Equipment:

- Software defined radio test bed:
- 10 USRP/USRP2 Motherboard 10/30

- 10 RFX900 daughter board
- 10 RFX2400 daughter board
- 10 824-960 MHz, 1710-1990 MHz Quad-band Antenna
- 10 2.4 GHz Vertical Antenna, RoHS Compliant
- Mobile wireless energy harvesting sensor networks
- 5 P2100 Powerharvester
- 5 Texas Instruments eZ430-RF2500 wireless board
- 5 GZ 115 supercapacitor from CAP-XX

1.1.23. UH Shared Resources and Environment

I. UH CACDS High-performance Computing Center and Data Science

The Center for Advanced Computing and Data Science owns and maintains several HPC platforms that support computational research at the University of Houston. Highlights include high-capacity storage; parallel and big data applications; high-speed, low-latency networking. It also manages site licenses for widely used software in order to make it readily accessible to faculty and students. The center continues to expand and add additional resources to facilitate the University of Houston's Tier-One Research goals. The center extended their newest cluster 'Sabine' by adding 52 compute nodes based on the newest hardware from HPE and Intel, referred to as gen10 servers, as well as 32 NVIDIA V100 GPUs, making Sabine a state-of-the-art facility.

- **Zeus cluster:** A 92-core Beowulf cluster: dual-core AMD 64bit, 2.4 GHz Opteron processors; each node has 2 GB RAM, 2 Network cards, and 330 GB disk space. There are two file server nodes, totaling 24 TB disk space, each with SunFire x4200 server, two 2.8 GHz Opteron processors, 8 GB RAM, fiber channel arrays for high speed connectivity, and 4 Network interface cards. There are two 17- inch KVM switch displays. Four Shared Memory servers: Each of the servers has 4 AMD Opteron 880 dual core processors (8 cores total); 32 GB RAM; 300 GB disk space; DVD and floppy drives; fiber attached disk storage with a capacity of 2 TB; Infiniband interconnect among the shared memory systems; and 2 Sun Infiniband switches 9P for high-speed communication. Nodes are installed with Linux CentOS 4.3. There are also 3 Alcatel switches, each with 24 ports that can possibly be used in the Beowulf cluster for internal message passing among the compute nodes. Currently, for this purpose, the system uses a 96 port Cisco switch.

- **Maxwell Cluster:** A shared campus resource housing public and private nodes in a condominium model with shared access to GPU and storage resources. CPU (3712 cores including all components): 112 - 8GB, 4 core (dual dual) AMD 2.2 GHz, 244 - 16 GB, 8 core (dual quad) AMD 2.2 GHz, 4 - 64GB, 32 core (quad quad) AMD 2.3 GHz, 24-64GB, 32 core (dual 16-) AMD 2.2 GHz, 4 - 128GB, 32 core (dual 16-) AMD 2.2 GHz, 2 - 512GB, 64 core (quad 16-) AMD 2.2 GHz. GPU component: 8 - 32GB Intel 3 GHz dual dual core w/ Telsa C2075 and Infiniband, 22 - 32 GB Intel 3 GHz dual dual core w/GTX570. Storage: 32TB of home directory space, 95TB of project directory space,120TB Lustre Filesystem w/4 OSS and 10Gb interconnects. Networking: star topology using a HP 5400zl with 10 Gb Ethernet interconnects to rack level switches and 10 Gb Ethernet for all storage; 1 Gb Ethernet nodes, 10 Gb Ethernet storage and switch interconnects

- **New Cluster**: A 35TFlop HP cluster is being added at present. All Enterprise servers are located in the University's Tier 1 datacenter. All servers are racked in two 40U dual powered APC server racks supported by a ProCurve 5000 series Gigabit switch. All servers in addition to Windows Server software firewalls are networked behind a SonicWall WXA 4000 physical firewall and VPN appliance. TIMES' dedicated mail servers are also protected behind a ProofPoint SPAM/Malware appliance. Secure and encrypted large file transfers are accommodated by a HIPAA compliant Biscom secure file transfer system housed and maintained by TIMES.

- **UH Visualization Theater**: Features seating for 30 people and a 16'x9' screen supporting 4K digital cinema resolutions up to 4096 x 2160 and both active and passive stereo 3D modes. The system is powered by a Linux workstation with 64 GB RAM and dual Opteron 6174 processors, 12 cores each at 2.2 GHz. Two AMD v8800 graphics cards drive two Sony SRX-S105 projectors with polarizing shutter filters at 4096 x 2160 pixels. The system is controlled by a RGB Spectrum Media Wall 4500 processor with 24 inputs and 12 outputs. The video processor provides digital and analog video inputs for TV/DVD/laptop computers. The workstation is compatible with most digital video formats. The room is also equipped with 7.1 surround sound and an ultrasound 3D tracking system for interaction with the screen.

II. Electrical and Computer Engineering (ECE) Department Facilities

Additional departmental facilities are available for color and black-and-white printing, photocopying, and other routine office tasks. Shared conference rooms and multi-media equipped presentation studios are also available in the building.

- **3D printer uPrint SE Plus 3D Printe**r: This is available for rapid prototyping.
- **Machine shop and Electronics Shops:** The ECE department at the University of Houston provides access to a staffed machine and electronics shop.
- **Scientific/engineering computer facilities**: A networked bank of 64-bit high-end computer workstation with Matlab's Simulink and various toolboxes is available for data intensive applications, including multidimensional signal processing, optimization, machine learning, statistics, motion analysis, neural interface design, an software development. Campus licenses are available for most major statistical analysis, visualization and scientific computation packages. For high-end 3-D and wide-angle visualization, we have access to the CAVE at the on-campus Texas Learning and Computation Center (TLCC)

III. The National Center for Airborne Laser Mapping (NCALM)

The mission of the National Center for Airborne Laser Mapping (NCALM) is to:

- Provide research-quality airborne light detection and ranging (lidar) observations to the scientific community.
- Advance the state of the art in airborne laser mapping.
- Train and educate graduate students with knowledge of airborne mapping to meet the needs of academic institutions, government agencies, and private industry.

NCALM is based at the University of Houston and is operated in partnership with the

University of California, Berkeley. The center is supported by the National Science Foundation and is associated with the multi-disciplinary Geosensing Systems Engineering & Sciences graduate program at the University of Houston. NCALM has a fleet of drones, including the Matrice 600 that is focused on in this project, as well as certified drone pilots.

IV. Educational Resources

The University of Houston Libraries, an ARL Library, provides a core of resources for faculty, graduate and undergraduate students in the areas of medicine and health science. Access to more than 5000 journal titles and over 2 million titles support the research efforts of our faculty and students in all areas. If a title is not available at UH, the Libraries provides the entire campus with Inter-Library Loan and document delivery (ILLiad) with an average turnaround time of 48 hours. These resources are supplemented by the resources available directly to our faculty and graduate students by the Texas Medical Center Library, one of the finest medical libraries in the country. Through a resource sharing agreement our faculty and graduate students have full privileges at the TMC library.

Relationship to Laboratory of Integrated Physiology (LIP): The CNBR grew out of, and remains closely affiliated with, HHP's Laboratory of Integrated Physiology (LIP). The LIP's capabilities in cellular and molecular level investigations of metabolism, energetics, and performance strongly complement the CNBR's capabilities in system level investigations. The close affiliation between these two research groups offers unique capabilities for performing multi-level studies of human performance. CNBR research studies requiring specialized cellular/molecular analyses have full access to the LIP wet laboratory facilities in Garrison Gymnasium on the University of Houston main campus. Additionally, the LIP has a seminar/teaching area (2100 sq. feet), a phlebotomy stations, one room for one- on-one private consultations, and a reception area.

V. The Wolff Center for Entrepreneurship at the University of Houston

Ranked #1 Undergraduate Entrepreneurship program in the Nation, the Wolff Center's mission is to empower the lives of students as they understand their values, articulate their dreams, and create outcomes. The Wolff Center for Entrepreneurship (WCE) is driven to deliver the best educational experience in and outside of the classroom. This experience is driven with world class instructors, mentors, tools, simulations and technologies. WCE students have the highest integrity and are driven to grow personally and professionally as they learn how to start and operate their own businesses. In the end, WCE students differentiate themselves in their ability to think, to lead and to connect. The Wolff Center for Entrepreneurship at the University of Houston C. T. Bauer College of Business prepares students to assume leadership roles in the business world, teaching them how to run their own business from the inception of an idea through its implementation. WCE was founded as a Center in 1991 and established in 1995 as a Major in Entrepreneurship under the Bachelor of Business Administration degree by the Texas State Committee for Higher Education. The visionary leader and founder William Sherrill won the prestigious Ernst & Young Entrepreneurship Educator of the Year Award in 1994 for his advancements in education. The RED labs, managed by Kelly McCormick offers programs and workshops for any type of entrepreneur. Learn more about our I-Corps program, our upcoming pitch competitions, our Side Hustle Series workshop, and so much more.

VI. The Engineering Program for Innovation and Entrepreneurship (EPIE)

The mission in EPIE at the Cullen College of Engineering is to create and foster a dynamic and exciting culture of innovation and entrepreneurship in engineering that serves both the University of Houston and the greater city of Houston. The EPIE offers courses, graduate certificates for entrepreneurship, student activities and competitions, seminars and workshops in collaboration with the WCE and the RED Labs. The EPIE is led by Dr. Haleh Ardebili.

1.2. IUCRC BRAIN at Arizona State University Site

Arizona State University/Overall Scientific Environment

Arizona State University (ASU) is one of the premier metropolitan public research universities in the nation. As of Fall 2019, ASU had a total enrollment of over 119,000 students. The state system also includes the University of Arizona in Tucson and Northern Arizona University in Flagstaff. ASU is a federation of unique colleges, schools, departments, and research institutes that comprise close-knit but diverse academic communities that are international in scope. ASU champions intellectual and cultural diversity and welcomes students from all 50 states and more than one hundred nations. ASU has 17 colleges and schools. Its six campuses are in Tempe, Glendale (ASU West campus), downtown Phoenix (which includes Edson College), Mesa (ASU Polytechnic campus), and Scottsdale (Skysong Innovations). ASU also has a virtual campus: ASU Online, whose graduate programs are ranked as among the best in the country. Arizona Learning Centers are located at Lake Havasu City and Eastern Arizona College; ASU Online offers a wide range of online degrees, online courses, and distance-learning programs and certificate programs for undergraduates and graduates. Thunderbird School of Global Management became a unit of the ASU knowledge enterprise in 2015, bringing with it 70 years of history and international accolades for executive education; it is among the top-ranked global business education institutions. Building on nearly two decades of unparalleled advancement, Arizona State University moved up to sixth out of 759 universities in the nation for total research expenditures among universities without a medical school, according to the latest National Science Foundation (NSF) Higher Education Research and Development (HERD) rankings. With a total of $639.6 million in expenditures in fiscal year 2019, an increase of nearly $22 million from the previous year, ASU research has continued an upward trend and is among the leaders in research. At No. 6, ASU ranks alongside MIT, University of California-Berkeley, Georgia Tech and Purdue University and ahead of Carnegie Mellon University, Princeton and the University of Georgia. Since 2002, ASU research expenditures have grown more than fivefold, going from $123 million to nearly $640 million today.

In the most recent HERD rankings, ASU placed No. 26 overall among public institutions (of 405 total) in research expenditures, putting it alongside the University of Texas-Austin, Purdue University, Michigan State University and the University of Arizona and ahead of the University of Virginia, University of Alabama, University of Iowa and North Carolina State University. ASU ranked No. 43 for all universities nationwide (of 916 total) with or without a medical school in FY19, placing it alongside the University of Illinois, the University of Texas-Austin, Purdue

University, Michigan State University and ahead of the University of Chicago, California Institute of Technology and Princeton University.

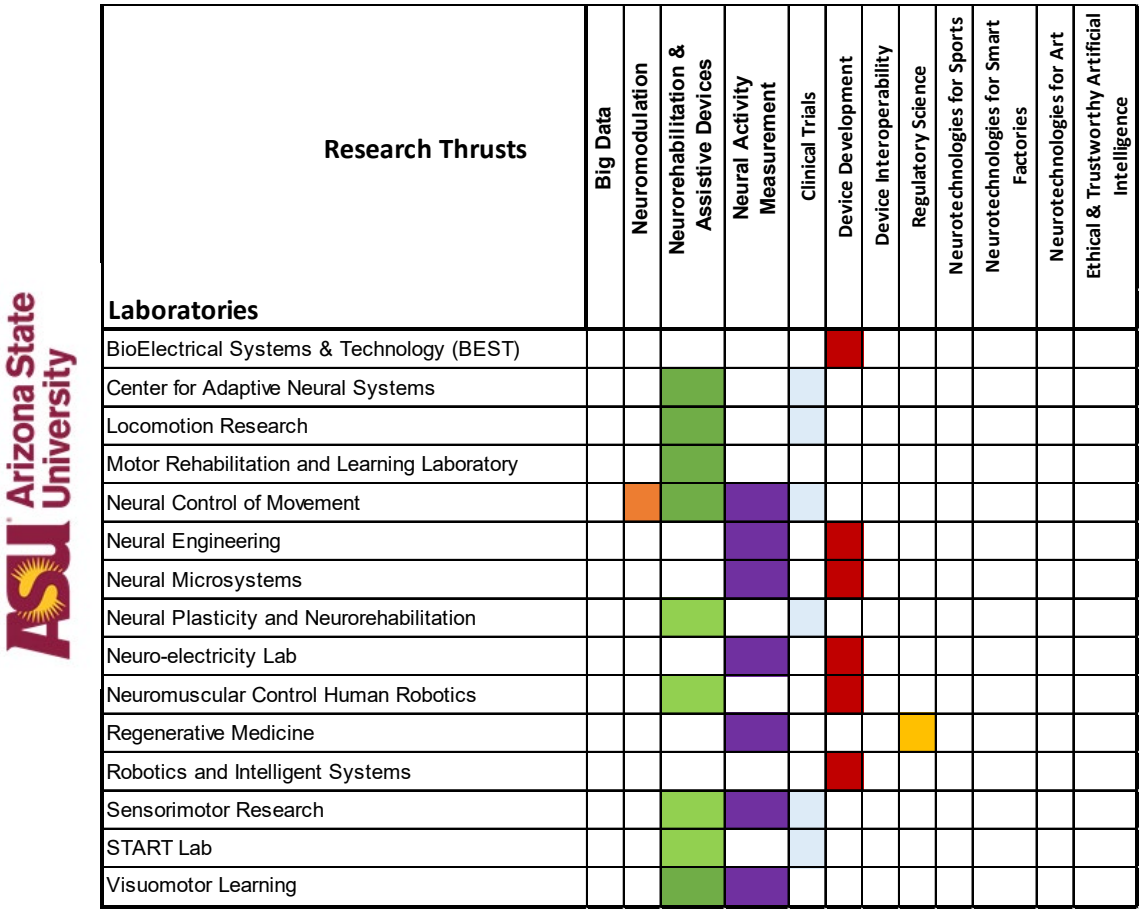

Figure 11

1.2.1 BioElectrical Systems & Technology (BEST) Laboratory, School of Electrical, Computer and Energy Engineering (Lab Director: Jennifer Blain Christen)

Overview: The BioElectrical Systems & Technology (BEST) laboratory, managed by Co-PI Blain Christen. The lab is distributed in several locations each meeting unique needs for the research. In addition, she and three other faculty members share a polymer microfabrication clean-room. She has access to the Arizona State University NanoFab. The NanoFab is accessible to the faculty members with an associated facility fee. These clean room facilities are both located in the Engineering Research Center along with her main lab and BSL-2 lab. She also shares a surgical suite with one other faculty member located in the Interdisciplinary Science and Technology Building I directly adjacent to the Engineering Research Center. Finally, she had a rapid prototyping lab located in the Interdisciplinary Science and Technology Building IV. Each of these building is within a 5 minute walk on the Tempe Campus of Arizona State University. Prof. Blain Christen and her graduate students have offices in the Goldwater Center, located diagonally across from the Engineering Research Center.

- **Computer Resources:** In addition to standard computing resources Arizona State University, the lab has software and computing resources for modeling, simulation, design,

and communication. All lab members have access to enable circuit design including integrated circuits, discrete components, board design, simulation, and layout (e.g. Cadence, PSPICE, HSPICE, Matlab, Silvaco, Eagle, etc.). The lab also has all software needed for the design and rapid prototyping of 3D printed devices (e.g. AutoDesk Inventor, AutoCAD, and Asura) In addition, the PI has two research licenses for COMSOL with additional modules for computational fluid dynamics, ray optics, wave mechanics, CAD import, and MEMS available for the project. The software is available in the Goldwater Center that houses the office space for the PI, students, and staff on the 3rd floor.

- **Offices**: The PI and Ph.D. students who will be working on this project have offices located in the Goldwater Center on the main campus of Arizona State University. All office and laboratory facilities are within 10 minutes walking distance.
  The BEST laboratory has two rooms both located in the Engineering Research Center. The first room is the main lab, a BSL-2 lab with separate areas for biological and chemical (wet) experiments, circuit prototyping and microfluidics testing, and optoelectronic characterization. The biological and chemical test area is equipped with a 4 foot Class II, type A2 biosafety cabinet and a 6 foot chemical hood. All standard wet laboratory equipment is available including a precision balance, serological and micropipetting devices, shaker, vortexer, and custom-designed teflon electrochemical cells and pogo-pin jigs for micro-scale wet experiments. It also contains a Nordson precision fluid dispensing system (sub-microliter) including Ultimus V dispenser, E3V 3 axis 300 mm x 300 mm stage robot, tip high detection imager, and heating unit. The system can dispense a range of fluids including: proteins, receptor molecules, piezoresistive materials, waxes, epoxies, metal wires, and more; the system enables custom fabrication of sensors, interfaces, and microfluidics on a variety of substrates.

  The circuit prototyping and microfluidics testing area has six workbench areas each with complete access to compressed air, vacuum, nitrogen, electrical and Ethernet lines. A dissection microscope with video imaging and a boom-stand microscope are present for assembly and video recording of experiments. An additional line is available to an H-cylinder storage area; this allows us to change the gas source as necessary for specific projects. It also contains a large work surface for assembly and wet testing. Finally, we have a soldering and electronics prototyping/assembly area with all the basic necessities. Equipment from the optoelectronics characterization area can be used in this area as well.

  The optoelectronics characterization area is defined by a blackout curtain meeting the BSL-2 requirements. It is equipped with a 6 foot active feedback, vibration-free optical table, two Keithley 2636A two channel source meters, a Keithley 2400 source meter, a 50 MHz arbitrary waveform function generator, a DS345 30 MHz digital arbitrary function generator, a Keithley 6485 picoammeter, an SR 770 FFT spectrum analyzer, an SR 560 low-noise voltage pre-amplifier, an SR 570 low-noise current pre-amplifier, an SRS 850 dual channel lock-in amplifier, Keithley precision digital multimeter, Keysight 34470A Digital Multimeter, an optical power meter, monochromator, several Tektronix oscilloscopes including DPO 3014 100 MHz, 2.5 GS/sec, Keysight MSOX3014T 100 MHz 4 analog/16 digital oscilloscope with integrated signal processing, several function generators, a capacitance meter, a variety of power supplies including programmable with data logging, and other ancillary testing components. It also contains a probe station with microscope and video imaging capabilities. In addition, an epi-fluorescence microscope with bright field and DIC capabilities as well as video imaging and still imaging is placed opposite the other equipment.

The second room is a BSL-2 biological testing and cell culture laboratory where biological materials are cultured, stored, and handled. The area is also designed for testing all biofluid samples including blood, serum, sweat, tears, etc. The laboratory is equipped with a class II, type A2 biosafety cabinet, two incubators, centrifuge, vortexer, water baths, sonicator, autoclave, liquid nitrogen dewar, refrigerator/freezer, balance, -85◦C freezer, phase contrast microscope with video imaging capability, two programmable syringe pumps, and ancillary hardware including a Millipore water filtration system (18MΩ).

The surgical suite is located in the Interdisciplinary Science and Technology Building I. This building also houses the vivarium and Department of Animal Care and Technologies. The room is equipped with a table for surgery; two stereotatic setups with linearly actuated manipulators for precision electrode placement; isofluorane setup with both mouse and rat nose cones; Intan Technologies 16 channel neural recording system; MouseOx small animal monitor for pulse oximetry, respiration, temp, pulse distension, repiratory distension, and activity; Sophysa intracranial pressure monitoring system; small (mouse) and medium (rat) surical boards with magnet fixators operated by push-button for multi-level locking jaw to grip retractors, wires, etc. We also have a number of custom multimodal small animal monitoring systems including EMG, optogenetic setup, pressure sensing, etc. The room also houses double-door drug locker maintained in accoradance with all IACUC and DEA requirements under the PI's DEA registration (RB0489600).

The polymer microfabrication laboratory is a class 1000 cleanroom dedicated to polymer microfabrication of microfluidic and bioMEMS devices, including soft lithography of PDMS. The cleanroom includes a mask aligner, laser writer for photolithography mask patterning or direct photoresist patterning, three photoresist spinners, evaporator for thin film deposition, profilometer, brightfield/darkfield/DIC microscope, one acid hood, two solvent hoods, a convection oven and an oxygen plasma chamber for surface treatment, cleaning, and bonding of microfluidic devices.

The Interdisciplinary Science and Technology Building IV rapid prototyping facility includes a chemical fume hood, biosafety cabinet, venting capabilities for the 3D printing equipment. She has a Moai Laser SLA printer with FEP vat and easy-level build plate option. It has a build volume of 13 cm x 13 cm x 18 cm with 70 micron laser spot and a 5 micron laser height resolution. Chamber heating has been added to the system along with additional UV curing chamber. The lab also have a Raise3D Pro2 Dual Extruder 3D printer for FDM printing with 5 micron planar resolution and 10 micron layer resolution, better than 0.8 micron positioning resolution in the X/Y planes. It has a print area of 12 inch by 12 inch by 11.8 inches. We have added high temperature 200 micron nozzles enabling printing at up to 300 degrees Celsius.

1.2.2 Center for Adaptive Neural Systems (ANS) at School of Biological and Health Systems Engineering (Lab Director: James Abbas)

Laboratories: The shared-use facilities of the Center for Adaptive Neural Systems (ANS) and its affiliated labs are housed within the Physical Education Building East (PEBE). The core ANS labs (approx. 800 sq. ft.) are configured for the development of rehabilitation technology, with a focus on neuroprostheses, and for neuromotor assessment in individuals with disabilities. The laboratories provide the capability to obtain non-invasive measurements

of biomechanical, neural control, metabolic and cardiorespiratory variables. The laboratories house several on-going studies involving human subjects with Parkinson's disease, spinal cord injury, or other disabilities. The affiliated shared-use labs (approx. 2000 sq. ft.) are adjacent to and integrated with the core ANS facilities. These labs, which are designed and equipped for projects that involve research on human locomotion, house an instrumented walkway for gait analysis, a dual-belt treadmill integrated into a virtual reality environment, and dedicated space for human subject examinations and preparation.

1.2.3. **Locomotion Research Laboratory** (Lab Director: Thurmon Lockhart)

Overview: The Locomotion Research Laboratory is located at the Physical Education Building East (PEBE) on the campus of Arizona State University at Tempe. The two-story building has office and collaboration spaces. The building features two laboratories, preparation or/ changing rooms, three conference rooms, numerous graduate student offices and student workstations. The shared-use facilities utilize more than 2000 sq. ft. of space that is configured for the development of rehabilitation technology and for neuromotor assessment in individuals with disabilities. The laboratory has space and equipment to enable non-invasive measurements of biomechanical, neural control, metabolic and cardiorespiratory variables. The facility includes a gait lab that is equipped for kinematic and kinetic analysis of overground locomotion and has a ceiling-mounted low-friction harness system for safe perturbation experiments. One adjacent room houses the Motek Medical GRAIL system which consists of a dual-belt instrumented treadmill capable of delivering pitch, sway, and surge perturbations. The gait lab and the GRAIL treadmill space both have ceiling mounted harnesses for safety that also allow rigorous testing of situation when balance is compromised. Figure 12.

Figure 12.. Virtual Reality lab and Gait laboratory

1.2.4. **Motor Rehabilitation and Learning Laboratory, School of Biological and Health Systems Engineering** (Lab Director: Sydney Schaefer).

Overview: The Motor Rehabilitation and Learning Laboratory (MRL) located in the Physical Education Building East (PEBE) on the Arizona State University Tempe campus, conducts human research on the aging brain that will be applied directly to clinical physical rehabilitative practice. We have a number of ongoing studies within the MRL Lab, as well as several community-based efforts. Research within the MRL Lab focuses on how the human nervous system learns new motor skills, and relearns existing ones during motor recovery following neural damage. Findings from this research are currently providing much-needed evidence to support and optimize the design of targeted rehabilitative training for older adults across a range of age-related physical disabilities. The PI's home department (School of Biological and Health Systems Engineering, SBHSE) has provided her with two renovated laboratory spaces totaling over 400 sq ft, just down the hall from her personal office. These laboratory spaces house the all necessary equipment for

this research proposal (see 'EQUIPMENT' below). In addition to the necessary equipment, the PI also has access to other equipment within the Neural Rehabilitation Engineering research suite, including multi-camera Vicon systems for motion capture, split-belt instrumented treadmills, Bertec 3-D force platforms, multi-channel telemetric electromyographic (EMG) and pressure pad modules combined with motion analysis software, in-house systems for measuring and modulating brain activity such as transcranial direct current stimulation (tDCS), transcranial magnetic stimulation (TMS), transcranial ultrasound stimulation (TUS), and electroencephalography (EEG). The PI also conducts magnetic resonance imaging (MRI) research in collaboration with a world-renowned neurological institute nearby (Barrow Neurological Institute), which is a designated test-bed for Phillips.

The PI's office is furnished with a desktop and laptop computer, printer, scanner, a long-distance phone line with voicemail, and internet access. Wireless networks provide for free, password-protected access across the entire ASU campus. The doctoral student supported by this proposal also has a dedicated office space with a desktop computer, laptop computer, printer, and secure internet access.

- **ASU Research Computing**: ASU provides necessary software, hardware, timely computer upgrades, and technology updates. For additional computing needs, ASU offers two supportive resources: 1) ASU Research Computing, which provides our community a leading academic supercomputing facility, maintaining a traditional high-performance computing environment, high-end data-intensive ecosystem and highly available 100 gigabit network. In line with the nation's most progressive universities, ASU Research Computing offers ease of access to ubiquitous computing capacity in the cloud, removing financial barriers to entry for faculty and student researchers. The program offers in-house expert support as well as a variety of educational and outreach opportunities; and 2) The Research Technology Office, which offers technology solutions and services to the university's faculty and research administration communities. Modern research involves data management, websites, collaboration portals, storage, "big data" analysis and other deliverables that call for a broad understanding of technologies available at ASU and elsewhere. RTO services include: Website development, Software engineering, Hardware configuration, Desktop support, Data management, Engagement oversight. Its technical advisors are trained to recommend solutions that address the complex and specific needs of faculty researchers and research administrators.

1.2.5 Neural Control of Movement Laboratory, School of Biological and Health Systems Engineering

1.2.5.1 Neural Control of Movement Laboratory, School of Biological and Health Systems Engineering (Lab Director: Marco Santello)

Overview: The Neural Control of Movement (NCM) Laboratory, located in the Physical Education Building East (PEBE) on the Arizona State University Tempe campus, is dedicated to motor control and learning research. The NCM Laboratory provides a setting for undergraduate, graduate, and postgraduate research on human motor control, as well as for performing collaborative research. The major research foci of the laboratory are control and cortical mechanisms of object grasping, sensorimotor integration, psycho-physics, and the effects of

musculoskeletal and neurological disorders on hand control. Research support, including equipment and space, is offered to undergraduate and graduate students, as well as postdoctoral fellows. There are currently four undergraduate students, three Master students, two PhD students, and two Postdoctoral Fellows working with Dr. Santello.

The laboratory area consists of two rooms. One of the rooms (PEBE 171, 700 sq. ft.) is used for experiments that use motion tracking, surface and intramuscular EMG recordings, and virtual reality. The second room (PEBE 174, 1822 sq. ft.) is used for transcranial magnetic stimulation and electroencephalography (EEG) experiments. The laboratory is completely computerized with "on-line" capabilities for data sharing and backup through a secure laboratory server. Part of PEBE has recently been renovated to create laboratory space for collaborative research among neural engineering and neurorehabilitation faculty from the School of Biological and Health Systems Engineering (Drs. Stephen Helms Tillery, Christopher Buneo, Jeffrey Kleim, Claire Honeycutt, Thurmon Lockhart) and the Mechanical Engineering program (Dr. Panagiotis Artemiadis). Additional space has been renovated for graduate students (PEBE 151,153, and 155; 25 desks; 1670 sq. ft.), a large conference room (550 sq. ft.), a break out room, and a kitchen. Office space has been renovated for eight postdoctoral trainees.

1.2.5.2. **Tyler Lab, Neural Control of Movement Laboratory, School of Biological and Health Systems Engineering** (Lab Director: William Tyler)

Overview: The total laboratory space of William Tyler, Ph.D. is approximately 1000 sqft in Bulldog Hall (BDH; BDH158C, BDH150) at Arizona State University in Tempe, AZ and 400 sqft in the ASU/Mayo Health Futures Building in Phoenix, AZ. We currently have space for approximately six students and/or postdocs and are able to conduct human research subjects research at both sites. We have approximately 250 sqft dedicated in the lab to conducting the manufacture and testing of ultrasonic neuromodulation research systems and components/mechanicals. We have additional space dedicated to field-testing and characterization of ultrasonic transducers. The transducer characterization rig consists of an acoustic test tanks, with calibrated PVDF hydrophones on scanning. The Tyler Laboratory at ASU has developed ultrasound (US) research platforms capable of rapidly scanning US stimulus space while simultaneously acquiring, analyzing, and grading biological responses in a high-throughput fashion. This research platform has broad flexibility and is currently used by many of the leading research groups in the world conducting work on ultrasonic neuromodulation. The platform is used to differentially stimulate peripheral somatosensory and brain circuits with US while simultaneously conducting EEG and during behavior in humans. Being at ASU has enabled the Tyler lab to cover this breadth of research by providing state of the art facilities and infrastructure.

ASU Biomedical Engineering Design Center: The Biomedical Engineering (BME) Design Center is a state-of-the-art, health care technology innovation facility housed within the School of Biological and Health Systems Engineering's dedicated instructional space. Encompassing over 10,000 sq. ft. of modern biomedical engineering product design and development space, the bioengineering design center provides an environment for students to experience the real world medical device product design and development. It is intended to dramatically improve the culture of innovation and entrepreneurship in global health technology development. Design integrated from freshman through capstone–specialized facility that includes rapid prototyping, machine shops, wetlabs and specialized computer software. In addition to its focus on product design and innovation, the Center also supports design teams that channel their effort to humanitarian campaigns. Thus far, students have designed numerous rehabilitation devices and diagnostic

heath care technologies for those in need in several African countries including Malawi, Zambia, Tanzania, Uganda, and Kenya, as well as rehabilitative technologies for earthquake victims in China. The Biomedical Engineering Design Center values partnerships greatly and works closely with industry professionals from various medical device companies, local health care clinical and research centers, and local entrepreneurial startup groups. Selected partnerships across these disciplines include Medtronic, C.R. Bard, W.L. Gore, Kinetic Muscles Inc., Machine Solutions, Vomaris Innovations, Inc. Mayo Clinic Scottsdale, Dignity Health, Maricopa Medical Center, Arizona Heart Institute, Barrow Neurological Institute, Banner Health, HealthSouth, Midwestern, Southwest Autism Research & Resource Center, AT Still University, BioAccel, Furnace, and SeedSpot. The core mission of the Biomedical Engineering Design Center is to prepare entrepreneurial leaders for the 21st Century. Leaders who can catalyze and drive the development of innovative and sustainable health care technology delivery systems to meet diverse global health care needs that can significantly improve the quality of life worldwide.

ASU Other Resources

ASU Graduate Program in Neuroscience: Devoted to provide an interdisciplinary program for training graduate students and postdoctoral researchers. We emphasize approaches that integrate several levels of analysis – molecular, cellular, systems, behavioral, cognitive - to investigate basic, translational and clinical questions about the relationship between brain and behavior. Students have the flexibility to tailor a program of study to meet their specific professional goals. PI's use an array of animals for understanding how nervous systems become adapted to their environments and as models for human neurological conditions. Finally, our program embraces the goals of the New American University at ASU in that it attempts to break from traditional disciplinary and organizational constraints to allow the university to harness its knowledge to transform society.

ASU Office of Knowledge Enterprise Development (OKED): ASU Knowledge Enterprise Development advances research, innovation, strategic partnerships, entrepreneurship, economic development and international development. These activities include: Research institutes and initiatives – empowering researchers to solve complex problems through university-wide, interdisciplinary research centers. Research development – connecting ASU expertise to key societal needs and securing resources to develop solutions. Research administration – assisting faculty and student researchers with funding opportunities, proposal writing, award management and more. Research ethics and integrity – ensuring compliance with federal, state and university regulations governing the ethical conduct of research. Research computing – providing supercomputing capabilities to faculty and student researchers. Strategic partnerships – collaborating with companies, nonprofits, governments and academic institutions around the world. Entrepreneurship programs – accelerating student, faculty and community ventures through training, networking, mentoring and support. Technology transfer – bringing new knowledge to market and protecting intellectual property rights. Economic development – advancing economic growth and a robust workforce in Arizona and the region. International development – propelling sustainable development in communities around the world.

ASU Barrett Honors College: Barrett, the Honors College offers academically rich and culturally diverse experiences across all four of ASU's campuses. Like any other ASU student, a Barrett student's home campus is determined by their major. Dedicated honors housing at each of the campuses provides a cohesive residential environment that enables students to experience campus life among a community of scholars - building lasting relationships with other

intellectually-driven and highly motivated peers from across multiple disciplines. Barrett's dedicated facilities at each campus provide meeting and study space, engagement and event programming, computer labs, and professional staff that are devoted to student success.

ASU OKED Instrumentation and Fabrication Core: The machine shop provides a wide array of design, prototyping, machining, and fabrication services to all ASU units using machineable, bendable, or weldable materials. Shop staff also specialize in ultra high vacuum (UHV) system repair and fabrication, and vacuum pump rebuilds. The Shop employs both additive and subtraction manufacturing methods. 3d FDM printing of over 50 different materials. All components are built to the design specifications set forth by researchers' designs for support of their research. The electronic services shop provided include low-level repair support for analytical laboratory equipment. (Gas chromatographs, Spectrophotometers, etc.) Repair general purpose test equipment. (oscilloscopes, digital multimeters, function generators, etc.). Labview: Install and upgrade older versions of Labview in Academic labs. Install associated hardware and provide purchasing advice for A/D boards and interface modules. Design & Fabrication: We can assist faculty and graduate students with electronic design and once the design is finalized we can do the fabrication. Ensure equipment and test setups comply with safety requirements. Training: User training for operating general-purpose test equipment.

ASU Fulton Engineering Education Outreach Program: The Ira A. Fulton Schools of Engineering K-12 engineering education team strives to build partnerships around the state of Arizona by designing and implementing sustainable long-term hands-on activities and curriculums that inspire K-12 students and show how engineering impacts our lives every day. This is done through a variety of on and off- campus activities, after-school programs, summer camps and collaborations with faculty and engineering student organizations. Our goal is to engage Arizona's K-12 students and create pathways that encourage them to become technically savvy, prepare for studies in science, technology, engineering and math (STEM)-related fields and pursue careers in engineering.

1.2.6. **Neural Engineering Lab** (Lab Director: Bradley Greger)

Overview: The ASU-Barrow Neurological Institute Center for Innovation in Neural Engineering (Neural Engineering Lab) is in the Biodesign facility on the Tempe Campus at Arizona State University and in the Barrow Neurological Institute at St. Joseph's Hospital and Medical Center. The labs are comprised of state-of-the-art facilities for conducting pre-clinical and clinical research studies of medical devices for neurological and neurosurgical applications.

- **High Performance Computing – ASU Agave Cluster:** The AGAVE cluster is composed of solid-state drives, DDR4-2400 memory scaling from 128GB to 256GB of DDR4 2400 to a 1.5TB of DDR4 2666 node. The capacity of the AGAVE cluster includes 8,512 cores on 324 hyper-converged, multi-processor X86 Intel Xeon E5-2680v4 "Broadwell" 2.4GHz processors and 1,280 cores on Intel Xeon Phi 7210 "Knights Landing" processors. The computational environment is supported by dual 100Gbps interconnected communication fabrics (Intel Omni-Path, Mellanox InfiniBand) and is interlinked to the campus Science DMZ, Internet2 and Data Transfer Nodes (DTN) by a 100/40GE core network to support both high-performance computation and high-throughput computing.

- **Office** – There is desk and office space for several students/postdocs and Dr. Greger located in the Interdisciplinary Research Building 1 at ASU. There are three desks for running experiments and two desks for other work located in the lab. There are three desk cubicles for students and postdocs and a separate office space and meeting room for the PI.

- **Laboratory** – The Neural Engineering Lab is in the Biodesign Building B at ASU and contains two acoustically, optically and electrically shielded experimental chambers; and electrical and networking infrastructure to support two electrophysiology setups. Each of these setups has an electrophysiological recording system (Neuroport, Blackrock Microsystems), which is capable of recording from 128 electrodes at up to 30 kHz per channel. This recording system is integrated with the computers needed to run behavioral experiments in real-time. There are wet and dry bench-top workstations for experimental preparation, and electronics and mechanical work.

1.2.7. Neural Microsystems Lab – (Lab Director: Jit Muthuswamy)

Overview: Neural Microsystems Lab Located in approximately 1000 square feet of laboratory space. The research thrusts of the lab are broadly in the areas of (a) neural interfaces and (b) neuromodulation. The Neural microsystems laboratory office space for the PI and graduate students is located on the first floor of the Interdisciplinary Science and Technology Building (ISTB1). The PI has a 150 sq ft. office in ISTB1 and students have 6 feet of desk space and two cabinets in a student bullpen adjacent to the PIs office.

1.2.8. Neural Plasticity and Neurorehabilitation (Kleim Laboratory), School of Biological and Health Systems Engineering (Lab Director: Jeffrey Kleim).

Overview: Dr. Kleim has extensive laboratory space in the Interdisciplinary Sciences Building within the School of Biological and Health Systems Engineering. The space includes a 100 square foot dedicated surgical suite for animal surgeries complete with digital surgical microscope, anesthesia mixer, autoclave and intracortical microstimulation equipment. It also includes 150 square feet of animal testing space with video equipment and motor training apparatus for motor performance. A 200 square foot dry laboratory houses recording systems for rodent behavioral analysis. Several Macintosh G5 computers with internet connections are available for data collection, analysis and manuscript preparation. Adequate office space for is also available for all trainees. Additional space within ISTB1 is shared with Dr. Sarah Stabenfeldt. This includes 1000 square feet of dedicated laboratory space and 1700 square feet of shared space.

1.2.9. The Neuro-Electricity Laboratory- (Lab Director: Rosalind Sadleir)

Overview: The Sadleir laboratory occupies approximately 1200 sq ft and is located in the north wing of the Interdisciplinary Science and Technology Building 1 (ISTB1) at the Tempe campus of Arizona State University (ASU). At the Barrow Neurological Institute, Dr. Sadleir has access to the research-dedicated 3-Tesla Philips Ingenia MRI scanner. This scanner is routinely used by the group to measure magnetic fields caused by neuromodulation current flows.

1.2.10. Neuromuscular Control and Human Robotics Laboratory (ASU Neurorobotics Lab) (Lab Director: Hyunglae Lee)

Overview: The lab is located in the Engineering Center E-Wing (ECE 116) at Arizona State University (approx. 1,600 sq. ft). The NeuroRobotics Lab (https://faculty.engineering.asu.edu/hlee) focuses on the design, development and control of robotic devices with applications to biomechanics, neuromotor control, physical human-robot interaction, and robot-aided neurorehabilitation. Overarching research goals include identification of mechanisms underlying human neuromuscular control; innovation of physical human-robot interaction by incorporating key principles in human motor control into robotics; and advancement of robot-aided neurorehabilitation for patients with sensory-motor impairment. The lab consists of a student office area and an area for conducting experiments and space for mounting the robot arm and other equipment. The student office area contains seven networked PCs. Dr. Lee is also using space in the Engineering Center C-Wing (ECC 117) at ASU, which was recently renovated to create a motion analysis laboratory for collaborative research among robotics faculty from the School of Engineering of Matter, Transport, and Energy (Drs. Sze Zheng Yong, Spring Berman, and Hamid Marvi). More specifically Dr. Lee is using this space (approx. 800 sq. ft) to conduct experiments that need motion capture capabilities.

1.2.11. Regenerative Medicine Laboratory, School of Biological and Health Systems Engineering (Lab Director: Sarah Stabenfeldt)

Overview: Dr. Stabenfeldt has 1000 square feet of dedicated laboratory space and 1700 square feet of shared space in the Interdisciplinary Science and Technology Building 1 (ISTB-1) at Arizona State University in Tempe, AZ. The laboratory is fully equipped for the material required for the proposed research. Equipment includes freezers (-20 and -80 °C), refrigerators, biosafety cabinet, 37°C cell culture incubator, centrifuges, balances, electrophoresis units, chromatography, pH meter, inverted microscope, spectrophotometer and bacterial incubator. Dr. Stabenfeldt's lab is certified to perform BSL-2 rated research.

- **Computer**: Dr. Stabenfeldt has 2 iMac computers, 1 laptop and 4 PCs in her laboratory for word processing, data analysis, performing literature searches, and presentation development. A 12-TB mirrored network storage server is also dedicated to Dr. Stabenfeldt's laboratory for data storage and backup.
- **Office:** Dr. Stabenfeldt has a 200 sq ft office in ISTB-1 and is located within 200ft of her laboratory. Student and Post-doc office space (~600 sq ft.) is also available to Dr. Stabenfeldt's laboratory in ISTB-1 and is located within 100 ft of the laboratory. Additional conference and meeting rooms are available to Dr. Stabenfeldt for group laboratory meetings.

Other Resources

- **Core Facilities in ISTB-1**: Dr. Stabenfeldt has access to shared laboratory space in ISTB-1 that includes walk-in 4 °C and 37 °C units, microscopy facilities (2 upright microscopes, 1 inverted bright-field/fluorescence microscope, and 2 stereomicroscopes), Li-Cor Odyssey NIR scanner, and analytical core lab (3 liquid chromatography systems, UV/VIS spectrometer, Raman Spectrometer, ELISA microplate system, and fluorescent

microplate system). Customized equipment needs can be supported by the Fulton School of Engineering's Machine Shop, Electronics Shop, and the College of Liberal Arts and Sciences' Glass Shop.

- **Keck Bioimaging Lab**: This ASU multi-user laboratory is dedicated to imaging from the macroscopic to the microscopic level. A wide a range of microscopes are available, including: a Prairie Ultima IV 2-Photon Microscope (in vivo imaging capabilities), a Bioscope system (equipped with objective and prism type total internal reflection fluorescence microscopy), an inverted epifluorescent microscope with Eppendorf microinjection system, a Leica SP2 Multi-photon Scanning Laser Microscope, a Leica TCS NT upright and inverted scanning laser microscope, a Zeiss Duo (combines high-speed line scanning, ultraprecise point confocal scanning, and spectral fingerprinting), a Molecular Dynamics Storm (PhosphorImager® capabilities along with non-radioactive fluorescent labeling techniques—direct fluorescence and chemifluorescence), a video & ratio imaging inverted microscope, a scanning probe microscope (includes scanning tunneling microscope and atomic force microscope). The Prairie Ultima IV 2-Photon Microscope is equipped with an Ultima IV in vivo laser scanning microscope with an X-Y translation stage and dual laser system that includes the Mai Tai and Tsunami lasers capable of MPE imaging, oblation and uncaging. The Leica SP2 is equipped with 3 visible lasers (Ar, Kr, and He/Ne) as well as a Spectra-Physics Tsunami infrared laser for multi-photon imaging. The Tsunami is pumped by an 8W Verdi pump laser, and may be tuned between 750 and 1050 nm. The SP2 features a spectrophotometric detection system, which allows users to precisely select the wavelengths of emitted light collected by any of four fluorescent photomultiplier tubes. Two nondescanned light detectors are also part of this setup, which allow for more sensitive light detection when scanning in multi-photon mode. The Zeiss Duo is a single system that combines high-speed line scanning, ultraprecise point confocal scanning, and spectral fingerprinting. The line scan mode can image 120 fps at 512 X 512 resolution.

- **Modeling and Simulation (Dr. Michael Caplan, ISTB-1):** Access to a PC workstation with COMSOL Multiphysics® software in Dr. Caplan's laboratory will be readily available.

- **Neurolucida Software (Dr. Jason Newbern, ISBT-1):** Access to an Olympus epifluorescent automated-tiling microscopy system with a high-resolution CCD camera with corresponding Neurolucida software in Dr. Jason Newbern's laboratory will be made readily available.

- **Electrophysiology (Dr. Trent Anderson, U of A COM):** Access to 2 state-of-the-art whole cell patch clamp recording rigs that are equipped for brain slice recordings will be made readily available. Dr. Anderson's laboratory is located at The University of Arizona College of Medicine Phoenix campus, which is only 10miles away from Dr. Stabenfeldt laboratory at ASU. Travel between campus requires only 15min driving. The two universities have a memorandum of understanding between IACUC committees to facilitate collaborative research projects between researchers. Therefore, distance between the researchers will not prove hamper the proposed research.

- **High Resolution Microscopy:** This national facility funded by NSF has nine state-of-the-art high resolution and analytical electron microscopes available for research use. Among the instruments are: JEOL-4000CX advanced fixed beam high resolution (0.17 nm)

imaging transmission electron microscope with a real-time image intensified television imaging and recording system, which gives a maximum magnification of about 30,000,000X; state-of-the-art analytical TEM/STEM microscope fitted with X-ray and electron spectrometers. This instrument is capable of 0.4 nm resolution, and has been modified to study the electronic structure of dislocations and other defects in semiconductors.

1.2.12. Robotics and Intelligent Systems Laboratory (RISE Lab) (Lab Director: Wenlong Zhang)

Overview: Robotics and Intelligent Systems Laboratory (RISE Lab) is located on the Technology Center building on the Polytechnic Campus at Arizona State University main campus and encompasses approximately 1100 square feet of laboratory space. The lab conducts research in the areas of wearable sensors and robots, soft robotics, and control and autonomy algorithm design for physical human-robot interaction.

1.2.13. Sensorimotor Research Group - (Lab Director: Stephen Helms Tillery)

Overview: We focus on sensorimotor learning and representations in the nervous system and neural mechanisms which enable the brain to carry out fine motor skills. In addition to core research within the Department of Bioengineering, the group also collaborates closely with the Visuomotor Learning Laboratory under P.I. Chris Buneo and Marco Santello. The group draws students from bioengineering and psychology programs at Arizona State University. The main thrust of this group remains cortical interfaces for neuroprosthetics. In particular, the group is focused on two aspects of these systems: 1) what are the abilities and limitations that come about due to neural plasticity and adaptation, and 2) how could tactile information be input back into the central nervous system. To these ends, the group uses a combination of human behavioral studies, neurophysiological recordings in humans and primates, and computer simulation. The overall goals of the research are twofold: to improve our knowledge of the brain, and to determine the best ways to use that knowledge to build computer-brain interfaces.

1.2.14. START Lab – (Lab Director: - Claire Honeycutt)

Overview: All experiments will be conducted either in Dr. Honeycutt's 1700 square foot lab located in a recently renovated building designed for collaborative research among neural engineering and neurorehabilitation faculty from the School of Biological and Health Systems Engineering (Dr. Stephen Helms Tillery, Dr. Christopher Buneo, Dr. Jeffrey Kleim, Dr. Bradley Greger, Dr. Thurmon Lockhart) and the Mechanical Engineering program (Dr. Panagiotis Artemiadis). Dr. Honeycutt's and Dr. Santello's spaces contain all of the equipment, computers, and software for the proposed research.

1.2.15. Visuomotor Learning Lab (VMLL) – (Lab Director: Chris Buneo)

Overview: **Human Laboratory**: This space is located in Bulldog Hall (BDH) on the Tempe campus of ASU and consists of three rooms (~10x8, 10x10 and 10x15) for experimental procedures plus additional student office space.

- **Office and Other Facilities:** The PI has a 150 sq ft. office in Engineering Center G-wing (ECG). Office space has been provided for the PI and graduate students in BDH. Additional desk space exists for students exists in each laboratory.

1.2.16. ASU Share Resources and Environment:

I. Center for Solid State Science (CSSS)

Clean–room and characterization facilities - Arizona State University has a well-equipped Center for Solid State Science (CSSS) and Center for Solid State Electronic research (CSSER).

II. Center for Solid State Electronic research (CSSER)

CSSERs research facilities cover almost 30,000 sq. ft. that includes C100/M3.5 clean room with equipment for:

- photolithography
- plasma etching
- metrology
- metal deposition

The molecular biology, Western blotting, immunoprecipitation, and biochemical assays will be done in the cell culture facility, which is a core facility for the department of Bioengineering.

III. The School of Life Sciences

There is the W. M. Keck BioImaging facility, a multidisciplinary shared resource accessible with reasonable user fees to everyone

IV. The Bioengineering Department

Operates **three core** research laboratories that support research in **Molecular, Cell and Tissue Bioengineering** which extends the department's capabilities with additional **cell culture, bioimaging and analytical equipment.**

- **The Core Bioimaging Facility** in 730 ft2 of contiguous space houses an inverted microscope (Leica DM IRBE) with fluorescence, phase contrast, and modulation contrast capabilities, a Leica Axioplan with fluorescence, brightfield, and phase contrast capabilities, a Leica MZFLIII stereomicroscope with brightfield and fluorescence capabilities and micropippetor and micromanipulator system. There is a color digital video camera (Optronics 750D) and a digital (Optronics Magnafire) for fluorescence and bright field image acquisition and analysis. Computer capabilities for the Bioengineering Core Imaging includes two Gateway Select 1000 (1 GHz) Systems for online image capture and processing and two Gateway Select 850 Systems for offline image processing and analyses. The Core Bioengineering Facilities also has a goniometer with computer imaging capabilities (Rame-Hart, Inc., Mountain Lakes, NJ) for surface analysis by contact angle measurements.

- **Core Cell Culture Facility** has 1000 ft2 with a main room reserved for standard cell culture. It contains four 4 foot biosafety cabinets, 4 CO2 incubators, 2 microgravity bioreactors, 2 Nikon light microscopes with digital imaging and Cohu cameras, water baths, centrifuges, cryostorage vessel, refrigerator, 2 freezers and -80 degree freezer. Also available is a pH meter, toploading and analytical balances, a UV/Vis spectrophotometer, microcentrifuge, a Beckman Optima Plus microultracentrifuge with 8 ml and 2 ml tube capacity, a speed-vac unit, sonicator, a microbial incubator, a microbial shaking incubator and a lyophilizer. The third area is the viral room, which contains a 6-foot biosafety cabinet, a Nikon inverted microscope, 2 CO2 incubators, and a water bath.
- **The Core Analytical Facility** provides equipment for basic protein, DNA and polymer characterization. The facility includes HPLC and FPLC capabilities, a UV/Vis spectophotometer, Circular Dichroism, and a Raman spectrophotometer. It also includes 2 capillary electrophoresis systems, a thermocycler, a ELISA microplate reader with six filters, a fluorescent microplate reader, and microplate washers. There is also a goneometer with video imaging capabilities. In addition to the core analytical facility equipment, the protein chemistry laboratory has circular dichroism, peptide synthesis, peptide sequencing, MALDI-TOF mass spectroscopy and amino acid analysis. Balances and sonication equipment are also present.

An adjacent laboratory contains an RC5Bplus centrifuge with SLA1500 and SS34 rotors, MilliQ water system, and autoclave. A TA instruments AR 1000 Rheometer and AKTA FPLC are also present.

V. Bioresources Facilities

These facilities offer DNA and peptide synthesis (Cruachem PS 250 and Millipore 9050), DNA sequencing (ABI 377), protein sequencing (Porton 2090) and amino acid (Hewlett-Packard AminoQuant) analysis. In addition HPLC (Beckman 125) and capillary electrophoresis (Beckman P/ACE available for purification of macromolecules. Molecular weight determinations of proteins will be made by a Vestec matrix-assisted laser desorption time of flight mass spectrometry (MALDI-TOF MS).

VI. Shops

Laboratory personnel have access to shared facilities (e.g. surgical suite, library, electronic shop, and machine shop) at the ASU. The Ira Fulton School of Engineering maintains an electronic shop and a machine shop for fabricating prototypes, instrumentation, and other components and assemblies for research. These shops are experienced in making custom-designed devices and parts used in behavioral and electrophysiology experiments, such as our primate chair, head-holder, and loudspeaker array. They are also providing timely services for equipment repair and modification. The PIs' laboratory has a full access to their services. In addition to the laboratory-specific resources described above, the PI has access to shared space for collaborative projects on human psychophysics and robotics work. This space consists of one room with dedicated motion capture (2 Optotrak 3020 camera bars, Northern Digital Inc.) and a large virtual reality setup that is configured for the study of arm movements by single or dual agents.

1.2.17. Facilities at our BRAIN industry partner sites

1.2.18. The CORE Institute and the MORE Foundation

Overview: The CORE Institute is a musculoskeletal and neurological clinical care system based in Phoenix Arizona. Started in 2005 as a three-physician practice with a mission to change the way orthopedic care was offered to their community, The CORE Institute now includes 188 medical care providers working out of 27 clinical locations with a total healthcare team of over 1,500 employees. The physicians and specialists at The CORE Institute are selected from the top tier of their class to ensure the highest standards of quality patient care are offered to each patient in the clinic, and in the operating room. Our physicians and specialists also recognize the importance of pioneering research, academics, community service and dedication to excellence in patient care.

The CORE Institute's providers subspecialize in areas ranging from the foot to the cervical spine and brain. Treatment approaches range from non-operative management of acute and chronic pain conditions to specialized surgical care such as joint replacement, spine surgery, soft tissue reconstruction and orthopedic trauma. In addition to our surgical specialty hospital in downtown Phoenix, our physicians provide surgical care through multiple large hospital systems across Arizona and Michigan. The clinical care team at The CORE Institute sees over 1 million patient encounters per year with over 200,000 new patients annually. In 2009, the senior leadership of The CORE Institute founded MORE Foundation, a 501c3 nonprofit foundation dedicated to research, medical education and charitable assistance programs in musculoskeletal health. MORE Foundation conducts dozens of clinical trials per year and houses advanced biomechanical testing and human motion research laboratories in the same building as CORE's headquarters. The 2 laboratories are surrounded by 7 offices and an open work area for staff and students. The Foundation has multiple computer workstations throughout its offices and shared workspace and maintains licenses to key research software. MORE Foundation employs 10 dedicated research staff, including certified clinical research coordinators and nurses, bioengineers, and study managers. MORE also welcomes and trains a variety of student interns each year. The team at MORE Foundation works closely with the clinical team and principle investigators from The CORE Institute to recruit patients for clinical trials and motion analysis studies.

Biomechanics Research and Surgical Skills Laboratory:

The MORE Foundation Biomechanics Laboratory focuses on musculo-skeletal effects of various orthopedic interventions, surgical procedures and implantable devices. These include implant construct strength analysis, fracture fixation, micromotion, joint range of motion, joint loading, muscle force and moment arm assessments etc. The team is dedicated to developing innovative and rigorous testing strategies that result in overall improved quality of life with the least risk of potential injury for patients. Additionally, the lab space allows for up to 7 stations for cadaveric surgical training and education of community surgeons, and allied medical professionals (PTs, OTs, nurses etc.) as part of continuing medical education (CME), device implantation training and proof-of-concept evaluations.

Primary Research Experience:

- Upper extremity (hand, shoulder, elbow)
- Spine (lumbar/cervical)

- Lower extremity (hip, knee, foot & ankle)
- Cadaveric musculoskeletal validations
- Pull-out and load-to-failure tests:
    - screw pull-outs, tendon strain, suture strength
    - construct strength tests (cadaveric bones, synthetic bones)
- Fatigue loading assessments with or without multi-fragment tracking
- Multi-axis, multi-segment range-of-motion (ROM) and loading assessments using 6-DOF robotic arm
- 3D CAD modeling, testing fixture design and fabrication
- Anatomical modeling & 3D printing using CT scans for pre-operative planning
- Bio-statistical analysis
- Preliminary, proof-of-concept testing
- Bio-specimen preparation
- Research protocol design, budgeting and grant submission
- Manuscript drafting and submissions to top peer-review journals
- Combined 35+ years staff experience

1.2.19. **Waymark Gardens**

Overview: Waymark Gardens, located in Glendale, AZ serves low income seniors who maintain an independent living status with or without assistance. The community houses 150 residents from age 62 or older or persons over 18 with a disability. The Waymark Gardens Board of Director strives to establish and ensure a safe and healthy living environment for the residents. After a town hall with residents conducted in 2019, it is realized that falls are a top concern for our residents. Our board has taken a proactive approach to supporting the residents and their fears. Based on findings of several onsite studies provided to the board of directors, we have authorized the hire of a Service Coordinator at Waymark Gardens. The social service professional will assist the low-income elderly individuals and persons with disabilities living in the Waymark Gardens community in obtaining the supportive services they need to continue to live as independently as possible in their homes. This Service Coordinator plays a critical role in working with one of our nation's most vulnerable populations. Many of these individuals have unmet financial and social needs, lack of family support, difficulty navigating through complicated healthcare and entitlement programs, mental and physical health challenges, and need help accessing services available in the community. While this Service Coordinator will be providing case management and non-clinical assessments, s/he will also be a facilitator of wellness, preventative health and other educational programs for the residents. The demographics are included below.

1.3. IUCRC BRAIN Tecnologico de Monterrey International Site

Tecnologico de Monterrey / Overall Scientific Environment

The Tecnológico de Monterrey, founded in 1943, is a private, non-profit institution committed to the quality of higher education in Mexico. Over the past 25 years, Tecnológico de Monterrey's academic quality assurance has revolved around five main premises: use of the admission standards and processes necessary for selecting the proper candidates, standardized learning assessment conducted internally and by outside agencies, graduate follow-up, evaluation of

institutional effectiveness via performance indicators, and the obtainment and maintenance of domestic and international accreditations for specific academic programs and the university as a whole. For Tecnológico de Monterrey, research is a strategical activity. Scientific knowledge is the engine that generates innovative solutions for our country´s economic, social and environmental development.

Monterrey is an industrial pole in Mexico and Latinamerica. This condition allows Tec de Monterrey to interact directly with main companies (factories, centers of design and research and headquarters) solving main problems. Our learning spaces and laboratories are modern and attractive to worldwide students and professors. Tecnológico de Monterrey has 60 professional careers, in the areas of Built Environment, Social Sciences and Government, Creative Studies, Engineering and Science, Business and Health; as well as various graduate programs: 41 master's programs, 12 doctoral programs and 16 medical specialty programs. In addition to offering the online modality with face-to-face equivalency and the executive modality. Tec de Monterrey also hosts specialized schools such as the EGADE Business School, the School of Government and Public Transformation and the EMIS School of Medicine. Tec de Monterrey has several labs where the students can test systems like those from industry. Our industrial partners offer seminars and workshops about recent advances and achievements on its company goals. Many of those goals are shared to Tec de Monterrey and we collaborate to solve them. We have the highest advanced manufacturing lab in Mexico focused on additive manufacturing and advance materials, and the Robotics Labs focused on disruptive mobility and unmanned autonomous vehicles. In these labs, the students will develop some specific practices and tests in order to improve our systems and their applied knowledge on biometric systems interacting with robots and vehicles. The tutors are research professors with experience in industry and applied research with scientific products in best ranked scientific journals in the world. Also, these labs are plenty of postgraduate students (junior researchers) which will share their practical experience with our guests. The Research and Technology Innovation Park (PIIT) (http://piit.com.mx/en/piit.php) is one of the strategies outlined in the project Nuevo Leon: Fostering the Knowledge based Economy and Society, which includes amongst its long term objectives to increase the per capita GDP of the State, through the transition from an industry based on manufacturing, to one based on knowledge, as well as through fostering a culture of high value innovation and entrepreneurship. Is an active member of the Association of University Research Parks (AURP) and the International Association of Science Parks (IASP), which incorporate the most recognized science and technology parks of the world. This helps the PIIT to have continuous exchange experiences towards its consolidation. The PIIT is at the 10th kilometer of the new highway to the Mariano Escobedo International Airport. The strategic, but not exclusive, areas being developed in the PIIT are: Nanotechnology, Biotechnology, Mechatronics and advanced manufacturing, Information technologies, Sustainable housing development, Medical services, Clean energies, and Advanced materials.

Laboratories / Research Thrusts	Big Data	Neuromodulation	Neurorehabilitation & Assistive Devices	Neural Activity Measurement	Clinical Trials	Device Development	Device Interoperability	Regulatory Science	Neurotechnologies for Sports	Neurotechnologies for Smart Factories	Neurotechnologies for Art	Ethical & Trustworthy Artificial Intelligence
Biometrics Systems/ Robotics lab												
Cobots Room												
Manufacture cell												

Figure 13

1.3.1. The Manufacturing Systems Automation Laboratory (Manufacturing Cell) (Lab Director: Adriana Vargas Martínez)

Overview: The laboratory Manufacturing Systems Automation Laboratory (Manufacturing Cell) is located the third floor of building LD, in room LD-306-M at Av. Eugenio Garza Sada 2501 Sur, Monterrey, Nuevo León, México, in the Engineering and Science School at the Tecnológico de Monterrey main campus, and encompasses approximately 112.57 square meters of laboratory space. The purpose of this lab is to ensure that undergraduate students acquire practical skills in automating manufacturing systems, their modeling, analysis, operation, and programming using industrial automation and integration technologies.

1.3.2. The Collaborative Robots Room (Cobots Room) laboratory (Lab Director: Adriana Vargas Martínez)

Overview: The laboratory 1.3.2. The Collaborative Robots Room is located in the third floor of the "Aulas7" building, in room A7-334 Av. Eugenio Garza Sada 2501 Sur, Monterrey, Nuevo León, México, in the Engineering and Science School at the Tecnológico de Monterrey main campus encompasses approximately 70.04 square meters. The laboratory is relatively new and its purpose is to serve professors and students as a real-life approach to the operation of collaborative robots in industrial settings. Lectures and regular classes are also held on the facilities with a capacity of 30 students.

1.3.3. The Robotics Laboratory (Lab Director: Adriana Vargas Martínez)

Overview: The Robotics Laboratory is located first floors (lobby) of the CETEC building, which is the iconic titled building of Tecnológico de Monterrey at Av. Eugenio Garza Sada 2501 Sur, Monterrey, Nuevo León, México. And encompasses approximately 93 square meters area. The space is used for work, leisure, research and collaboration, and for research purposes in the fields of robotics and tele-engineering. The laboratory is also used by undergraduate and postgraduate students to perform research and educational activities in competitive and research robotics. The lab provides practical knowledge to design integrated systems for the automation of land or air transportation, energy network automation, industrial automation, or virtual home or building

automation, using and integrating electronic, computer and telecommunications technology for the development of remote measurement, monitoring and process control platforms.

Figure 14

1.4. IUCRC BRAIN at the Universidad Miguel Hernandez de Elche International Site (Lab Director: Jose M. Azorin)

Universidad Miguel Hernandez de Elche / Scientific Environment

UMH is a young and public university, distributed from the north to the south of the province of Alicante (Spain), in the municipalities of Altea, Sant Joan d'Alacant, Elche (main campus), and Orihuela. The university campuses cover 97 hectares, there are 75 university buildings, two more are currently under construction, and there are almost 247,000 square meters of built-up spaces. The teaching structure at the UMH is comprised of 7 faculties: Faculty of Experimental Sciences, Faculty of Fine Arts, Faculty of Health and Social Sciences, Faculty of Medicine, Faculty of Pharmacy, Faculty of Social and Legal Sciences of Elche, and the Faculty of Social and Legal Sciences of Orihuela. There are also 2 schools at the UMH: School of Engineering of Elche and School of Engineering of Orihuela. In addition to these units, the UMH is home to 4 research institutes: Institute of Bioengineering, Institute "Center of Operations Research" (CIO); Institute of Research, Development and Innovation in Healthcare Biotechnology of Elche; and Institute of Neurosciences. There are also 27 university departments. In terms of academics, the UMH offers 26 bachelor's and 2 dual bachelor's, 50 master's, and 13 doctoral programs. Complementing this official training are 55 Refinement programs (27 University Expert, 16 unique master's, 6 Advanced University Diploma, and 6 University Specialist). Average research resources committed to the UMH (research income) over the past five years have been 10,534,105€, and our position in the 2019 U-Ranking of Spanish Universities in terms of Innovation and Technological Development is third. In the 2019 ISSUE-P ranking for productivity of Spanish universities, the UMH is eighth. In addition, according to the seventh edition of the ranking by the BBVA Foundation and the IVIE, the UMH is among the top Spanish universities. Furthermore, UMH is the second Spanish university in Industry, Innovation, and Infrastructure in the Times Higher Education rankings.

Laboratories \ Research Thrusts	Big Data	Neuromodulation	Neurorehabilitation & Assistive Devices	Neural Activity Measurement	Clinical Trials	Device Development	Device Interoperability	Regulatory Science	Neurotechnologies for Sports	Neurotechnologies for Smart Factories	Neurotechnologies for Art	Ethical & Trustworthy Artificial Intelligence
Behavior Analysis												
Brain-Machine Interface Systems												
Group of Design and Development of Bioactive Molecules												
Motor Control and Learning												
Ocular Neurobiology Group												

Figure 15

Overview: The following laboratories from Brain-Machine Interface Systems Lab are available: P1018 and P1019, both located at Module 2, Floor 1, of Innova Building, Miguel Hernández University of Elche in Spain. The other groups of BRAIN UMH; Motor Control and Learning Lab, Behavior Analysis Lab, Ocular Neurobiology group, Group of Design and Development of Bioactive Modules, have their own rooms. The BMI Systems Lab has several facilities to perform BMI experiments, a room dedicated to the register of brain signals during movement and with the exoskeleton, a space with stairs and a ramp to perform experiments in several ground conditions, and a room with several computer workstations for data analysis and software development and a meeting room.

Figure 16