AREAS OF FOCUS

Introduction

BRUCE: We’re about to begin a series of lessons that will give you an introduction to the areas that make up biomedical engineering.

You will quickly notice that there are many topics and many lessons. As we’ve noted earlier, biomedical engineering is anything that includes some element of biology and some element of engineering. Since both are very large and diverse, their intersection is huge.

This means that we cannot possibly cover everything. Try as we might, we will likely overemphasize some areas and underemphasize others.

You’ll also notice the many overlaps among the areas of this multidisciplinary field. Biomolecular science and computation or informatics will appear in most of the lessons. Also pervasive will be biomedical imaging and ties to medical practice.

The overall picture is of a field that challenges definition but is rapidly evolving and vibrant and is looking for talented individuals to shape the future.

As you learn about the various areas, I want you to think about what you might want to do. What areas particularly pique your interest? Where could you see yourself? Think about your own strengths and where you’d like to apply them. Along the way, you're going to meet some of the leaders in these fields, as well as those just setting out. And you'll learn how they got there. Do you see yourself in any of them?

When we're all done, we'll explore how you can chart your chosen career path and education.

LESSON 4: PRACTICAL APPLICATIONS

INTRODUCTION

BRUCE: Let's start with one of the most practical of biomedical engineering specialties, clinical engineering. Then we'll transition to a brief overview of how biomedical engineers are involved in diagnostics and therapeutics, a theme that will recur throughout this course.

We then emphasize the hugely important area of rehabilitation and rehabilitation engineering, and end with its very interesting offshoot, the area of performance enhancement.
CLINICAL ENGINEERING

BRUCE: One of the oldest and most practical areas of work for biomedical engineers has been clinical engineering, generally taken to be the purchasing, repair, and maintenance of instrumentation in hospital settings. This is, of course, exceptionally important and ever more challenging as the modern hospital and clinic grow more and more dependent on sophisticated and varied instruments.

In recognition of the type of skills required, the job has grown to be referred to as Healthcare Technology Management.

Clinical engineers can be based in hospitals, where responsibilities may include managing the hospital’s medical equipment systems and working with physicians to adapt these systems to meet the specific needs of the physician and hospital.

In industry, clinical engineers work in medical product development, from product design to sales and support, to ensure that new products meet the demands of medical practice.

While professionals with appropriate degrees and experience can obtain training and certification, there are no Bachelor’s level programs in Clinical Engineering, but there is a strong professional organization -- the American College of Clinical Engineering -- which can help those interested in the field.

Diagnostic and Therapeutic Systems

BRUCE: I want to turn briefly to the role of biomedical engineers in diagnostic and therapeutic systems. In this role, they bridge from practical clinical engineering to the development of more advanced instrumentation. These engineers work in industry, with the goal of improving the performance of the many instruments found in medical practice. Their goal is not to understand a disease, but rather to provide instruments that are more precise and efficient. For example, smarter ECG machines to help with the diagnosis of heart disease; or higher intensity ultrasound to more efficiently ablate tumors.

A rapidly growing area is in clinical decision support systems. These may be built into individual pieces of equipment or used to integrate the volumes of data collected daily on each patient. We will explore many of these systems, including state-of-the-art research, later in the course.

Working in the Clinical Setting

PAOLO BONATO: The Motion Analysis Laboratory focuses on assessing motor abnormalities, and that’s used both clinically, for the purpose of informing surgical procedures, as well as for research purposes to develop new technologies to facilitate or augment mobilities in patients.

IAHN CAJIGAS: This lab primarily focuses on two types of work: one is being, providing clinical service to patients in gait analysis, and on the other hand we do research in the area of wireless sensors and robotics for rehabilitation.
CHIARA MANICELLI: So we do a lot of studies with comparing different technologies and see which one works better for certain situations, or to see if some kind of therapies have impact that can be shown over time and try to quantify that.

PAOLO BONATO: I saw the opportunity of actually moving our research activities in the hospital setting, and that’s absolutely the best way to both benefit from the interaction with physicians as well as test the technology that we develop directly with patients.

IAHN CAJIGAS: As engineers, it’s really easy to get kind of focused on a project and kind of forget about why you’re really doing it, whereas being around patients all the time really reminds you of what the design challenges are and also why you’re doing what you’re doing.

PAOLO BONATO: If your laboratory is set in an engineering school, you spend a lot of time thinking of problems that you want to address, if you work in a hospital, problems, they come to you through the door.

ROSS ZAFONTE: So we like to establish things as an iterative loop; a loop where people are going back from the laboratory to the clinic and then back to the lab again, refining our questions.

PAOLO BONATO: Can we maximize mobility in amputees, people who lost their lower limbs? Can we get spinal cord injury patients to be mobile again? Can we get stroke survivors to use their upper limbs in a functional way? And these are all questions that we’re helping clinicians to address by providing technology that either augments function in these patients or allows us to do a better job retraining motor functions by both tracking responses to interventions as well as facilitating interventions through robotics.

CHIARA MANICELLI: We do a lot of testing of new technologies, so you can imagine that the challenges there are just grow exponentially because they’re not product that they already are being marketed. A lot of times we’re basically trying to change the product or to direct the building of the products in different directions.

IAHN CAJIGAS: Since we’re really doing active research in the field of robotic gait rehabilitation, we’ve formed a collaboration with the company that developed the Lokomat. And so we’re actually able to tap in using our own software and change the way that the robot works.

THERAPIST: I’m going to make you walk a little bit faster now. Okay?
PATIENT: Okay.

IAHN CAJIGAS: So we can not only use the assessment settings that are in there already and the training settings, but we can go in, develop our own ideas and then test them out in a very controlled environment.

CHIARA MANICELLI: So being able to be in contact with patients and do actual clinical work so seeing how the inventions and the technology impacts the life of the people, it’s pretty amazing.

ROSS ZAFONTE: The goal of our work is not only to integrate engineering principles into the clinical treatment protocols and refine what we do in a better way, but it’s really a very simple edict: It’s to use
our collective capabilities to get better every day for our patients. We look to take a step ahead. If we’re doing the same thing in 10 years that we’re doing today, then we haven’t done a good job.

REHABILITATION ENGINEERING

BRUCE: Rehabilitation Engineering is the application of science and technology to improve the quality of life for people with disabilities. This can include designing augmentative and alternative communication systems for people who cannot communicate in traditional ways, making computers more accessible, developing new materials and designs for wheelchairs, and making prosthetic legs for runners in the Paralympics.

As our aging population faces disabilities from stroke and other conditions, this field has grown remarkably; not only in its close collaboration with physical therapy, but also in technology. We’re seeing robotics for strengthening a stroke victim’s leg or arm muscles, while also retraining the patient’s neural system.

There is rapid growth in the monitoring of rehabilitation patients and the elderly. Wearable devices are becoming widespread, including fall detectors. There are even "Smart Houses" where a patient can be monitored for a combination of safety, exercise encouragement, rehabilitation, and research.

Neural Protheses
NOTE: To learn more about other approaches to neural prostheses, see Lesson 6.

LEVI HARGROVE: My area of focus is on controlling powered prosthetic arms and powered prosthetic legs, so making systems that are easy for people to use who have lost their limbs. How do we integrate motor control and sensory information in the brain to control these prostheses in an intuitive way? So we use a neural interface and typically what we try to do is measure biological signals, usually from the muscle, electromyogram. And we use signal processing, engineering approaches to decode what the person is trying to tell the prosthesis to do. And so, there is a neural interface. You’re not interfacing with the nerves directly or the brain directly, but you are figuring out what the person is thinking or trying to do by interpreting those signals.

Muscle kinda’ acts to amplify nerve signals, and so we can measure them externally from the skin surface. And in that way, we can make a system that people can put on and it’s chronic; the electrodes touch the skin, we can measure the signals through the skin. It’s very non-invasive, although it does have some limitations. And so, we are trying to figure out the best way, which muscles to read from, where we should place our electrodes. And in the case of legs, what other data sources do we have available? Can we use inertial sensors like are in your cell phone? Can we use load cells and combine them with these biological signals to get a better picture of what the person is doing and how they’re interacting with their environment? So those are the key questions that we ask.

And then we’re in a hospital, Rehabilitation Institute of Chicago. It imbeds research and patient care, and so we’ll do a lot of clinical trials as well. So we will measure people, send them home with their devices for six weeks, eight weeks, years are what we’re aspiring to. And then we measure and see how they’re using their device at home and in their home environment.
Getting Them to Patients

LEVI HARGROVE: Unless it gets out there on patients, in my opinion it doesn’t have the impact that I want to have. I understand that there’s basic science, and that needs to be done, it’s just not my focus area, so I wanna develop technology and see people using it in making their life better every day. Some technologies we will license to established companies, sometimes we’ll do a closely aligned spin-off company; it just depends on the situation. Some of the work that we are developing on controlling arms, that’s actually has been commercialized. It’s a small company called Coapt. So that is available to the masses now.

We do more basic research when necessary, but we really try to translate the technology to patients in the near term which is kind of two, three, four, five years. My personal goal and when I came to Chicago, so that’s eight years ago, was to make sure that what I did in my PhD dissertation didn’t collect dust and get it onto people, and we’ve been able to successfully achieve that. It took a lot of work, but now people can buy that, they can use it.

Now my next goal is to do the same thing for legs; so there are ten times more individuals with leg amputations than arm amputations, but the field is newer. Motorized prosthetic legs is a newer field. So, what I wanna do now is make sure that we get a good intuitive way to control leg prostheses of the patients. And so that’s something that’s gonna take another probably five, 10 years, who knows. And then move into exoskeletons because I think those also will be a really good technology to help a lot of people with spinal cord injuries, stroke. So that’s longer term.

Working with Patients

LEVI HARGROVE: I went through undergraduate electrical engineering. Certainly more fun to interact with people than interacting with amplifiers for example, or computers. So, for me the most interesting thing is I get to talk with people every day, so I’m probably working with a patient, maybe three, four times a week for two to three hours, me or my team. And so that’s really fun. You get to try, measure things from the people, you get their feedback.

When you see an amputee put on an arm and move it for the first time, or put on a leg and stand up and walk with a motorized leg, and you have an experiment that’s planned for two or three hours and you can’t do anything just because you’re watching them play or move their prosthetic hand which they haven’t been able to do for sometimes decades, that’s a fun thing. No problem scrapping the experiment and having them come back in on a second day to do it, that’s just really rewarding.

Exoskeletons

HOMAYOON KAZEROONI: The area that I’m conducting research and development is robotics and exoskeleton systems. Exoskeleton systems are robotic devices that are worn by people with disability or disorders, perhaps spinal cord injury people or stroke patients. These devices can be also used for workers that they manipulate heavy objects or perhaps they go to wrong posture during daily maneuvers. So these devices not only they augment a person’s ability to do certain things, but also it alters the forces in their spine and muscle forces, so it reduces the risk of injuries.
It’s a different view of a bionics here. It’s not about jumping over the building, it’s not about carrying heavy loads, it’s not about being supermen and scaring people. In fact, robotics is really not as scary. It’s just a simple machinery, it’s very humble. Aluminum, steel, computers, sensors, all of that stuff that we have, totally non-organic stuff, we’re putting together to give a little help. So sometimes I get actually quite disappointed, I see these movies that are really good but it actually portrays some level of violence and it’s just far removed from what I’m thinking about. I’m talking about in a stroke patient, or people with mobility disorders of all kinds, to just simply stand up and walk; these are really, really basic things, but quite enabling...

MICHAEL MCKINLEY: I don’t have the ability to fix the spinal cord but I do have a pretty good ability to make machines and make machines that are really good at what they do.

WAYNE TUNG: We basically start from the problem and go from there. I’m passionate about it. Like I want to find a solution and I think there is a solution out there. And I basically just, like, think about the problem everywhere I go. And then, if you think about it for long enough, eventually you come up with the solution.

MINERVA PILLAI: A lot of what is constantly being done here is problem solving. You know, we’re on our third knee because initially something is designed and then you have to make it better and better and better. I don’t think you can expect it to be perfect after the first shot; especially in what we’re doing, because not a lot of people have done this before.

JASON REID: I’ve been developing the code for this robot for a bit over a year now. It needs to be very reliable, one hundred percent of the time. Failure is never acceptable.

MICHAEL MCKINLEY: And we work together almost as a two-part team, where we’re bringing the science and they’re bringing the insight from their reality.

DANIEL FUKUCHI: Unless you’ve been in a wheelchair, it’s very difficult to see all the very small details in what a person would actually need within an exoframe.

AUSTIN WHITNEY: That’s what makes our project so sexy; is it’s alive, it’s real. And my job is basically to help them transform this computer model and help show what’s gonna really happen to it in real life.

WAYNE TUNG: Do one, one step.
AUSTIN WHITNEY: On step and hold?
WAYNE TUNG: Stop, yeah...Okay.

STEVEN SANCHEZ: This machine helps with a couple different things: rehab, exercise and involved in our everyday lives. I am not the robot. I wear the robot. I feel much more myself and human-like being in this device, being able to stand up eye to eye with somebody. It’s strange that this robot makes me feel more a part of this planet than the wheelchair does.

HOMAYOON KAZEROONI: And maybe their walk is not perfect, maybe it’s robotics, maybe uh, it’s a little uh, uh, not natural or organic, buy hey, this is beginning right now and when I think about it more and more and more I realize these are the people that will be the first users of bionics.

(Cheers)
ADMINISTRATOR: Congratulations.
AUSTIN: Thank you.
ANNOUNCER: Austin Whitney!
(Cheers)
AUSTIN: We did it, Kaz.

HOMAYOON KAZEROONI: This exoskeleton might seem rather revolutionary to some. But I don’t see it. I see a natural progression from the same glasses and hearing aid and prosthetic device to something a little bigger maybe.

**PERFORMANCE ENHANCEMENT**

BRUCE: It’s only a short jump from Rehabilitation Engineering to Performance Enhancement. You can think of rehabilitation as being performance enhancement for people who have lost one or more ability. But many people without disabilities desire performance enhancement as well. In its simplest form, consider the training that an athlete undertakes.

Bioengineering technologies can be employed to bring individuals to higher levels of performance; especially on focused tasks. In the area of mental performance, the goal may be to reduce fatigue or enhance decision-making. Where physical performance is key, a person could be coupled with a biomimetic device, such as a force-multiplying exoskeleton or a surgical robot.

**Monitoring Pilot Fatigue**

FABIO BABILONI: When we have to drive some complex machine like an airplane, which kind of activity is going on in the brain? The airplane that cost 100-million of euros, and the airplane, I mean all the computer, does know nothing about the mental state of the pilots. The idea is to improve the communication between man and machine, in order to help the pilots to drive better and to understand more precisely the mental effort or the mental fatigue of the drivers. And those signs can be detected by electroencephalographic and signal processing techniques. So it is possible to generate device in a strict future, in the near future, that are able to detect when the pilots will be unable to cope with the situation, and allows to the computer of the airplane to help them. It is well known that when you have to make a decision in a strict amount of time, the more information you have, the less you use such information.

PLANE: (beep) Landing gear.

FABIO BABILONI: So it would became critical when the pilots have to do brisker and rapid decision, that the correct amount of information would be displayed, not too much. The cockpit in the future it will be tidy glass cockpit, in which the computer will put the instruments. So which kind of information the computer have to put on there for the pilots in order to improve the quality of the decision of the pilot. the research I performing is to evaluate the current degree of overload of the brain when compared to the information offered.

This is a measure that we upload to the computer, the on-board, cockpit computer, to decrease the number of information when the overload it will be significant; otherwise the pilot will decide by themself. On the basis of previous information; not what is has been showed, just previous, what do you think is good.
PLANE: (beep) Landing gear.

FABIO BABILONI: On the ground is for training, for training pilots, so when they became trained with this system they understand better their limits. When they are on the sky, on the clouds, this technology alerts the people mainly to the computer on the board in the close future, to understand better the situation.

PLANE: 50, 40, sink rate, sink rate.

PIETRO ARICO: I'm a post-doc in bioengineering, I work with Professor Babiloni, and I work with him because my research field is oriented to operational environment and to assess the mental states of the user in order to improve the life of operators during a day's work. Our purpose is to monitoring the mental states of the user like for example, mental workload, attention, emotional states by using the EEG activity of the user. Because for example, there are several questionnaires that normally you can use, but of course if they are professional, they can lie, they cannot say the truth. So in this way, for example, we demonstrated that one technology was better than another one by using the objectivity of the operators. Right now we are working with air traffic controllers, pilots, skydivers, and our purpose is to, for example, readapt the working flow or the instrumentation depending from the mental workload of the user.

FABIO BABILONI: So the critical technology in order to do that so-called the dry electrodes. So electrodes that are able to detect brain signal without any gel, any preparation; few electrodes, a couple, maybe, and the capability but this is no longer a problem of signal processing algorithms, to detecting real-time mental force. This is no longer an issue. But the technical issue, those dry electrodes and wearable sensor. It is a something that can be reached in a couple of years.

HOW THEY GOT HERE

Paolo Bonato
PAOLO BONATO: I did start really as a traditional electrical engineering department and my background at the time I did my PhD was very much oriented towards a hardcore single processing. So that was very traditional in that regard. And eventually I developed an interest for translational research and when I say translational, I mean really in the trenches. And I enjoy very much doing this type of work, given the direct impact that it has on patients.

Chiara Manicelli
CHIARA MANICELLI: So I got both my degrees, my Bachelor and a Master, in Italy, so that’s where I’m from. And I came over to the Spaulding Rehabilitation Hospital during my last year of my Master. I wanted to write my thesis about gait analysis and wearable technology, so this was an excellent place to work with. And my professor, my advisor back home and Paolo knew each other. So he send me here for one year, and then after my thesis I decided to stay and just keep working in the lab.

Levi Hargrove
LEVI HARGROVE: I was trained at the University of New Brunswick in Fredericton, Canada and they had a very strong biomedical engineering department, and so they had some of the leaders of the field study
there and they developed different prostheses. So I was fortunate to take a undergraduate course from a man named Philip Parker, and he was just a great teacher, a good mentor. And then had the opportunity to go to Chicago where there’s more patients, you get to see more people. So it just kinda’ went from there.

**Homayoon Kazerooni**

HOMAYOON KAZEROONI: I was developing robotic devices and systems and I realized the best combination would be robots and human, rather than replacing humans, you actually put ‘em together because you’re combining human intelligence with robotics’ strength and I lost a little interest on robotics by themselves, and I knew the performance of these machines are quite limited, and it is limited, actually. If there is going to be a disaster, I want people being in there coming and saving me with all kind of tools rather than sending me a robot that’s gonna take 20 minutes to figure out if the door handle should be going down or up or whatever that is. So, there’s a sense of urgency, people need that and they need it to move a little bit faster.

**EXERCISES**

**Using Wearable Devices for Rehabilitation**

BRUCE: Do you have any wearable devices? A Fit-Bit? A heart rate monitor when you run? A distance or elevation tracker for your bike ride? Which of these devices do you think would be of assistance for someone after a stroke? How does your device communicate with your smart phone or with the Cloud and how might a rehab specialist make use of the data?

**Explore the ACCE Web Site**

Explore the ACCE (American College of Clinical Engineering) web site to see what background you need in order to gain training and certification in clinical engineering.