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DEVICES TO AID MOBILITY: BIOMEDICAL ENGINEERING-FOCUSED UNDERGRADUATE SENIOR CAPSTONE DESIGN PROJECTS

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ABSTRACT

In order to meet the increasing societal and market demand for a diverse and well-trained Biomedical Engineering (BME) workforce, the University of the District of Columbia (UDC), the nation's only urban land-grant institution, the District of Columbia's only public institution of higher education, and a historically black college and university (HBCU), nurtures BME activities focused on exposure, training and cultivation through research and experiential learning. Undergraduate design projects and research-based learning opportunities in BME are key program ingredients. This paper presents the former (i.e., three, BME-related undergraduate senior Capstone Design projects that target devices to aid patient immobility) namely, the design of: 1) an ankle foot orthosis, 2) an upperlimb robotic hand prosthetic, and 3) a chairless chair lower limb exoskeleton.

A current focus of the UDC BME program is Rehabilitation Engineering (i.e., interventions and devices aimed at aiding those with mobility impairments). We briefly discuss the necessity for rehabilitation-focused, biomedical-related undergraduate experiences and training for underrepresented minority students at UDC, in particular, undergraduate engineering education through multidisciplinary BME projects that foster hands-on creativity towards innovative designs.

In addition to critical design experiences and undergraduate training in BME, devices may have the potential to develop into new commercial technologies and/or research projects that will aid and enhance the quality life of individuals suffering from a wide-range of mobility-related issues.

INTRODUCTION

The Societal & Market Need for Biomedical Engineers

Biomedical engineering (or BME) is the application of engineering principles and design concepts to solve medically-related problems that affect human health. BME is a relatively new and rapidly growing field which has emerged due to the fact that individuals are living longer and there is a growing demand for increased quality of life.

BME is projected to have among the highest increases in job-demand over the next several years (i.e., employment of biomedical engineers is projected to grow 23 percent from 2014 to 2024 which is much faster than the average for all occupations) [1]. Thus, undergraduate training, design and research experiences in BME must be enhanced to echo societal needs and the growing job-market demands.

Within the field of BME, Rehabilitation Engineering (RE), is the application of engineering sciences to design, develop, test, evaluate, and apply technological solutions to problems confronted by individuals with disabilities. Below we discuss the need for BME, and hence, RE involvement by women and minorities, as well as the need for BME/RE-related education and research at HBCUs.

The Need for a Diverse Biomedical Engineering Workforce

Minorities comprise a significant portion the United States population. However, they still remain underrepresented in the fields of science, technology, engineering, and mathematics (STEM). It is a well-known fact that women, African Americans, and Hispanics have been historically: 1) underrepresented in STEM employment, 2) less likely to enroll in a science or engineering major at onset and 3) less likely to remain within STEM majors to degree completion [2]. In 2011, women comprised about half of the workforce (~ 47%). However, in the STEM fields only 26% of STEM workers were women and 74% were men. In BME, ~16% of workers were female and ~84% were male; strikingly, Hispanics and African Americans only comprised ~3 - 4%, respectively, of all Biomedical Occupations [2]. HBCUs may hold the answer to creating a more diverse, well-equipped BME workforce.

Although HBCUs comprise only 2% of our Nations' degree-granting undergraduate-serving colleges, *amazingly, they produce 41% of all African American STEM degree holders* [3]. Increasing expectations of individuals and patients to maintain an active and healthy lifestyle has led to the demand for further development of new technology and health care in order to assist those with medically-related problems. However, HBCUs need to react and better prepare students for the workforce to meet this growing demand [3].

UDC is one of only very few HBCUs with a degree-granting program in BME; this program is currently housed within the Department of Mechanical Engineering within the School of Engineering and Applied Sciences (SEAS). As the District's only public university, a HBCU, and an urban land-grant institution, it is UDC's mission to "build a diverse generation of competitive, civically engaged scholars and leaders" with core values in: Excellence, Collaboration, Sustainability, Innovation, and Integrity. Experiential learning experiences, such as those described by the BME/RE Capstone Design projects herein, are needed at UDC for the following reasons: 1) Over the next decade, BME is projected to grow the fastest of all occupations. Education and exposure to research development in BME enhances UDC student knowledge and employability; 2) Currently, there are very limited undergraduate BME degree offerings at HBCUs. BME/RE Capstone Design projects allow a gateway to expose students to societally-relevant needs. This may encourage them to further pursue careers, advanced degrees and/or research towards aid those suffering from disabilities; 3) The Metropolitan Washington DC region offers students and professionals unique opportunities that few cities provide. This region is a prime locale for rehabilitative research in that world-renowned institutions (e.g., MedStar National Rehabilitation Hospital (NRH), National Institutes of Health (NIH), and others) are all within close proximity to UDC. Potential interactions between UDC and these institutes would not only enhance student experiences, but may also lead to rehabilitation research and development.

METHODS

The UDC Engineering Capstone Design projects described took place over the 2017-18 academic year. In the fall-term, students were instructed via in-class lectures on design conceptualization, modeling, approximation techniques, optimization, prototyping and testing. They were also provided design case studies to study and review, then present to the class and instructor. To gain perspective, they were also exposed to guest lectures from professional researchers from MedStar National Rehabilitation Hospital (focused on stroke-patient gait research and stroke-patient upperlimb robotic rehabilitation research), as well as the Department of Veteran Affairs. In summary, during the fall-term lecture portion of the course, students were taught the following:

- The importance of good design practice
- Thorough problem definition and understanding (e.g., via case studies & guest lectures)
- Defining objectives and determining design constraints
- Including analytical and physical modeling in designs
- Professional oral and written communications
- Diligent level of effort toward well-defined milestones (i.e., via Gantt Chart)
- Effective record keeping & documentation (Project Meeting Minutes)
- Discipline in meeting personal and group obligations & commitments, as well as teamwork with mutual respect

To re-iterate from above, students were mentored about the timetables, design considerations and constraints, considering the end-user, teamwork and time management, and others. Design teams were composed of UDC Mechanical Engineering students, with various levels of exposure to BME projects and research. Design teams of 3 – 5 individuals per team worked on the following undergraduate senior Capstone Design projects that target patient immobility, namely: 1) an Ankle Foot Orthosis (e.g., for stroke patients), 2) an Upper-limb Robotic Hand prosthetic (for upper limb amputees), and 3) a Chairless Chair (e.g., for elderly).

There were weekly group meetings between the project advisor and students to brainstorm ideas, discuss any design concerns, as well as guide and mentor the students. Routine, formal group update presentations were held at the end of Fall 2017, January 2018, February 2018, and March 2018, with the final project report and presentation in April 2018. Through the regular student-presentations, students were taught how to present key points and findings and, overall, how to put together and give a presentation. The groups' initial prototypes were completed in March and students evaluated their designs. The following points were stressed throughout the spring-term:

- Prototype construction
- Design evaluation & meeting design constraints
- Design improvements & Future Work
- Completion of the final design report & team presentation to the Department and SEAS

DISCUSSION

An overview of the students' completed designs is provided.

Ankle Foot Orthosis (AFO)

The purpose of this project was to design an ankle-foot orthotic device aimed towards assisting persons that suffer from a drop-foot condition (e.g., stroke survivors). The AFO student design team were able to create a device that: 1) was comfortable and ergonomic compared to existing ankle-foot orthoses; 2) mimicked the force distribution of an individual with a regular gait, and 3) was stiffer and provided sufficient resistance & support of the dropped-foot. Different than commonly used passive AFOs, this AFO (Figure 1) was produced from casted rubber (the bottom of the AFO was similar profile to one's actual foot), a base made of polypropylene, and a supportive & compressive ankle sleeve (as opposed to the more commonly used rigid plastic that rubs against one's calf).

Figure 1. Ankle Foot Orthosis

The students evaluated their design using a self-made design evaluation form (which compared their prototype to current passive prototypes on the market), the Tekscan Forceplate (to show improvements in AFO pressure distribution, observed as a more similar to a distribution seen in regular gait compared to other AFOs), and Creo Parametric Software Simulation (to observe that the deflection of the AFO prototype was decreased with the casted rubber reinforcement).

Upper-limb Robotic Hand prosthetic

Millions of individuals in the United States are currently living with limb loss, with veterans and children being the leading recipients of prosthetics. Thus, there is a pressing need for realistic and functional upper limb prosthetics. The purpose of this project was to design of an upper-limb prosthetic that could interface with an Open Bionics robotic hand attachment. The forearm attachment was casted out of silicon rubber, and was hollow such that electronics could be housed inside the arm (e.g., to interface the robotic hand with surface electromyography). The students incorporated an adjustable shoulder sleeve attachment and gel socket aimed at amputee comfort. The entire prosthetic (including Open Bionics robotic hand) only weighed 2 lbs. To create the forearm and adjustable shoulder sleeve, costs were \$100 total not including the bionic hand which is only a fraction of what current prosthetics may cost. The design is shown below in Figure 2.

Figure 2. Upper-limb Robotic Hand prosthetic

Chairless Chair

The purpose of this project was to design a lower limb exoskeleton device that allows a person to go from a supported sitting to standing position without the use of a chair. Industrial workers, surgeons, and elderly could benefit from such an apparatus. The students' initial design prototype (out of aluminum) was ~\$100 and final design (out of carbon fiber) was < \$ 200, much lower cost compared to the current chairless chairs on the market; the cheapest we observed was \$1000 but they can be > \$6000.

Further, other chairless chairs were non-adjustable, but here our device could be locked in different settings (e.g., 135°, 90°) for a person to adjust his/her desired seating position. Further, our design allowed for adjustable heights, something previously not implemented in other chairless chair designs. The students constructed their first prototype out of aluminum and it weighed 3.2 kg (Figure 3, top). Then, using similar measures, they constructed sleeker, lighter and stronger final, design out of carbon fiber which weighed only 0.65 kg (Figure 3, bottom).

Figure 3. Chairless Chair Exoskeleton: *Top* - Initial Design Prototype #1 made out of aluminum; *Bottom* - Final Design Prototype #2 made out of carbon fiber.

CONCLUSIONS

We observed that the students became much more excited about the hands-on activities, than our previous experiences working with them in "regular" courses. Through seeing their designs develop, they were nurtured creatively. Further, through thinking of the end-users, who they would be (e.g., mobility-impaired stroke survivors, amputees, and elderly), and how their lives would benefit, this gave the students a perspective, and added motivation, on how their designs could impact people's lives for the better.

Professional development took place on multiple levels. Professional oral (presentations) and written communications (reports) greatly improved throughout the fall and spring terms. More abstract thinking (i.e., defining objectives and determining design constraints, as well as analytical and physical modeling in designs) was cultivated in that the projects were more open-ended than textbook problems. Keeping on task to meet milestones, record keeping and documentation (e.g., via Project Meeting Minutes), and teamwork were also greatly enhanced skills. Through being competent and proficient in all of the above skills, we hope this will enhance our students' employability and ability to contribute to the BME (and/or STEM) workforce.

The long-term aim of activities such as those described above is to provide a firm foundation for UDC minority students, further enhance the educational experiences, and foster designs and research at UDC in BME/RE. We also aim to offer and encourage engineering students involved with the mobility-related projects mentorship and experiences which allow them a contiguous path towards successful careers in STEM and/or BME/ME research and technology. Furthermore, another goal is that once the products are developed, they perhaps can be used for research purposes (e.g., student M.S. theses at UDC) and also to evaluate their effectiveness on patient rehabilitation. Products can be further modified and improved, with the potential for industrial commercialization. The BME/RE design projects may be used towards research and/or further design development aimed at improving the overall quality of life and independence for those suffering from moderate to severe immobility.

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