Prosthetic Robots in Healthcare

Surinder Kaur

Abstract

A *prosthesis* is an artificial body part that replaces a missing body part. Many people are in need of various types of prostheses, including injured soldiers, people who live in war zones, or people who have been in accidents. Biomedical engineers design prostheses for these *amputees* so that they can live as easily as others.

The most important characteristics for a good prosthetic leg include strength, durability, longevity, shock absorption, lifelikeness and comfort. Biomedical engineers research and design new ways to create prosthetic legs that have all of these characteristics.

My 12th grade Medical Science course are introduced to biomedical engineering and the technology of prosthetics. As they create a model prosthetic lower leg, testing strength and considering its pros and cons, they learn about issues and materials that biomedical engineers consider in designing artificial limbs.

Rationale

Robotic lower limb prostheses can improve the quality of life for amputees. Development of such devices, currently dominated by long prototyping periods, could be sped up by predictive simulations. Advanced prosthetics have for the past few years begun tapping into brain signals to provide amputees with impressive new levels of control (Doi.org, 2018). Patients think, and a limb moves. But getting a robotic arm or hand to sense what it's touching, and send that feeling back to the brain, has been a harder task. Medicine has progressed a lot since the Civil War, but amputations haven't. Once a limb is sliced off, surgeons wrap muscle around the raw end, bury nerve endings, and often attach a fixed prosthesis that is nowhere near as agile as the flesh-and-blood original. Better robotic limbs are available, but engineers are still figuring out how to attach them to people and give users fine motor control. Now, a team of researchers and clinicians has developed a simple surgical technique that could lead to prosthetics that are almost as responsive as real limbs (Osborn et al., 2018).

The biggest barrier to lifelike limbs is that signals can no longer travel in an unbroken path from the brain to the limb and back. Scientists have developed several ways to bridge the gap. The simplest is to place electrodes on remaining muscle near the amputation site (Doi.org, 2018). For finer control, doctors can use severed nerves themselves to relay the signals, through electronic attachments. But when they aren't rejected by nerve tissue, such attachments tend to receive weak signals. A stronger signal comes from attaching nerve endings to small muscle grafts that amplify the signal and relay it using electrodes (Bellman, Holgate and Sugar, 2018). But even this method fails to take advantage of a simple biological solution for joint control: the pairing of agonistic and antagonistic muscles. When you contract your biceps to bend your elbow, for example, your triceps on the other side of the joint stretches, providing resistance and feedback. Together, such opposing muscle pairs let you fluidly adjust a limb's force, position, and speed (Bellman, Holgate and Sugar, 2018).

The purpose of this unit is to improve students' knowledge of prosthetic robots which has not been discussed in high school curriculum. By the end of this unit, students will be able to describe the different types of prosthetic robots and how it helps those in need. The school that I work in serves students from ninth grade through twelfth grade. A partnership high school with the Franklin Institute. It provides a rigorous, college-preparatory curriculum with a focus on science, technology, mathematics, and entrepreneurship. Students learn in a technology-infused, project-based environment where the core values of inquiry, research, collaboration, presentation, and reflection are emphasized in all classes. It is a special admission school which has a total population of 500 with 125 at each grade level. The English Language Learner population at the school is 4%. The special education students consist of 12% of the school population. 43% of the students receive free and/or reduced price lunch. The student demographics are as follows: African American-36%; Lation-12%; Asian- 11%; White-34%; Other-8%.

Background

The evolution of prosthetics is a long and storied history, from its primitive beginnings to its sophisticated present, to the exciting visions of the future. As in the development of any other field, some ideas and inventions have worked and been expanded upon, such as the fixed-position foot, while others have fallen by the wayside or become obsolete, such as the use of iron in a prosthesis. The long and winding road to the computerized leg began about 1500 B.C. and has been evolving ever since. There have been many refinements to the first peg legs and hand hooks that have led to the highly individualized fitting and casting of today's devices (Robert, 2009).

In addition to lighter, patient-molded devices, the advent of microprocessors, computer chips and robotics in today's devices are designed to return amputees to the lifestyle they were accustomed to, rather than to simply provide basic functionality or a more pleasing appearance. Prostheses are more realistic with silicone covers and are able to mimic the function of a natural limb more now than at any time before (Robert, 2009).

In exploring the history of prosthetics, we can appreciate all that went into making a device and the generations of perseverance required to ensure that man can not only have four limbs but that he can have function. The human body is a template for many state-of-the-art prosthetic devices and sensors (Osborn et al., 2018). Perceptions of touch and pain are fundamental components of our daily lives that convey valuable information about our environment while also providing an element of protection from damage to our bodies. Advances in prosthesis designs and control mechanisms can aid an amputee's ability to regain lost function but often lack meaningful tactile feedback or perception (Dellon and Matsuoka, 2007).

Slipping into a robotic exoskeleton that could enhance strength or even serve as a prosthetic limb is a highly appealing concept and contrary to popular belief, exoskeletons that aim to impart superhuman strength are not new and can be traced back to 1965 (Dellon and Matsuoka, 2007). By 1970 only one arm had been made to work and although it could lift 750 lbs (341 kg) and responded according to specification, it weighed three-quarters of a ton. No further work was reported. In the mid-1980s, there was Pitman, the pet project of an engineer at the Los Alamos National Laboratory, which was a strength-enhancing suit that took its movement cues from brain-scanning sensors in a helmet. This also failed to reach production. These efforts ran into fundamental technological limitations: computers were not fast enough to process the control functions necessary to make the suits respond smoothly; energy supplies were not compact and light enough to be easily portable; and actuators, which are the electromechanical muscles of an exoskeleton, were too sluggish, heavy and bulky. Nevertheless, exoskeletons continue to feature highly in science fiction and film buffs will recall the cargo-loader suit worn by Sigourney Weaver to battle with the Alien queen in Aliens, but what are the real prospects for these devices? Robotic systems for assistance and rehabilitation focus on providing missing movements and sensing, providing safer environments, and providing environments that make regaining movement-related function easier and faster. Robotic prosthetics and exoskeletons will provide dexterity, natural mobility, and sense of touch to missing or paralyzed limbs. Individuals suffering from hip or knee conditions can use a robotically intelligent walker or wheelchair to help prevent common accidents like slipping (Dellon and Matsuoka, 2007).

Robotic rehabilitation not only provides consistent and efficient therapy without tiring, it also has the potential to enhance the therapy beyond the abilities of the practitioner. When this field reaches its peak, the benefits to society will be enormous. We will be able to replace entire limbs with prosthetics that can replicate one's own biological functions precisely, casting a natural outward appearance and requiring minimal upkeep. With a safe and intelligent robotic rehabilitation unit, patients can recover faster and more naturally without feeling resistance to repetitive exercise or the need to be in a hospital (Dellon and Matsuoka, 2007). These are neither dreams nor hubris, but goals to strive towards. However, these goals cannot be achieved without tackling some technical challenges that lie ahead. As a robotic community, many of the challenges in the field of prosthetics are common to other physical human-robot interaction (PHRI) fields: power, size, weight, and safety. When users are disabled or elderly, these challenges must be met even more rigorously. Furthermore, perhaps our biggest and most unique challenge ahead is to grow closer to the fields of neuroscience and movement science, and to the clinicians in these fields, so that more natural controls may be realized, all towards the goal of robotic solutions actually being employed in medical practice (Dellon and Matsuoka, 2007; Doi.org, 2018).

The goal of modern prosthetics is to replicate the function of the replaced limb or organ in the most capable and discreet fashion possible. However, even the most advanced, commercial, transtibial prostheses available today only passively adjust the position of the ankle during the swing phase of gait and return a portion of the user's own gravitational input (Dellon and Matsuoka, 2007). To greatly improve the quality of life of a transtibial amputee, new technologies and approaches must be used to create a cutting-edge robotic ankle prosthesis which can perform on par with, if not outperform, the equivalent able-bodied human ankle. Initial attempts by us and others have had great success in providing the natural gait power and motion through all ranges of walking speeds. A new design is presented which governs both the coronal and sagittal angles and moments of the ankle joint to potentially provide unprecedented levels of athleticism and agility among transtibial amputees (Bellman, Holgate and Sugar, 2018).

Objectives

My goal is to have students develop an understanding about the importance of Prosthetics in the healthcare and how it helps a person with conducting daily tasks. During this unit (Biomedical Engineering and the human body, 2018) students will also answer various questions through investigations, mini lessons, hands on experiments and the experience of building a three dimensional model of a prosthetic. By the completion of this unit students should be able to answer the following questions:

Describe the engineering design considerations that go into developing quality prostheses.

List characteristics and features that are important for a prosthetic leg.

Analyze a prototype prosthetic leg and make suggestions for design.

How to deal with common prosthetic problems?

Strategies

This is a four-week unit. As this is a four-week unit, I intend to break the unit apart according to the questions I listed under objectives. I plan to employ the use of many different learning processes in order to help all students achieve an understanding of prosthetics in healthcare. This unit will begin with vocabulary studies. The vocabulary studies will include quick writes, an activity where students respond in writing or by drawing to a vocabulary word or phrase about the prosthetics in lab notebook. It will also include Vocabulary sentence writing and a review Kahoot game.

During this portion of the unit, students will begin with making an engineering connection research. One aspect of biomedical engineering is researching and designing better prostheses. Biomedical engineers are continually improving these parts so that amputees can lead full lives. Those who need an artificial leg must have a structurally stable one to replace a critical part of their skeletal system.

Classroom Activities

In order to achieve the objectives, students will engage in a variety of classroom activities and investigation during this four-week unit (Biomedical Engineering and the human body, 2018).

Week One - Students will be introduced to the vocabulary for the unit using Vocabulary sentence writing and a review Kahoot game.

Vocabulary/Definitions

- *amputee* - a person who has had a limb removed.
- *biomedical engineer* - an occupation that includes designing artificial body parts.
- *bioengineering* - the use of artificial tissues, organs or organ components to replace damaged or absent parts of the body, such as artificial limbs and heart pacemakers.
- *engineer* - a person who applies understanding of science and math to creating things for the benefit of humanity and our world.
- *prosthesis* - an artificial body part to replace a missing one. Plural: prostheses.
- *prosthetics* - a specialty of medicine and engineering that designs, constructs and fits artificial limbs and body parts (prostheses).
- *prototype* - an original, full-scale, and usually working, model of a new product, or new version of an existing product.
- *Body* - the physical structure of a person or an animal, including the bones, flesh and organs.
- *Bone* - any of the pieces of hard, whitish tissue making the skeleton in humans and other vertebrates.
- *Biomedical* - relating to both biology and medicine
- *Design* - purpose, planning, or intention that exists or is thought to exist behind an action, fact, or material object
- *Engineering design process* - a series of steps that engineers follow to come up with a solution to a problem.
- *Human body* - the entire structure of a human being.
- *Leg* - each of the limbs on which a person or animal walks and stands.
- *Skeletal system* - the internal framework of the body
- *Skeleton* - the supporting framework, basic structure, or essential part of something

- *Strength* - the quality or state of being strong, in particular.
- *Structure* - the arrangement of and relations between parts or elements of something complex.

Week Two - During this week, the students learn about the Prosthetics in healthcare and especially focusing on engineering design.

Engineering Design Pre-Activity

(Biomedical Engineering and the human body, 2018)

With the Students

1. Pre-activity Discussion: Introduce the topic of biomedical engineering and prosthesis, then lead a pre-activity discussion and brainstorming session so students gain a basic understanding of the various prosthetic requirements and material resources to meet these needs.

Remind students that in brainstorming, all ideas should be respectfully heard. Take an uncritical position, encourage wild ideas and discourage criticism of ideas. Solicit, integrate and summarize student responses, giving prompts as necessary, and recording ideas on the board. Ask:

- What features would make a useful prosthetic lower leg? (Possible answers: *strength, stability, durability, longevity, shock absorption, lifelikeness, comfort*.)
- How can you achieve some of these qualities, using the provided resources? (Possible answers: *Use the plunger head for a comfortable knee support, use rope or duct tape for connection to the body, use tube or pipe or wood for strong and sturdy support*.)

2. Explain that the students will design and create their own prosthetic lower legs. They will test their *prototypes* by bending a knee and resting it on the prosthesis. The goal is to provide all the important features that have been discussed — strength, durability, longevity, shock absorption, lifelikeness and comfort. Then they will figure out some way to connect their prostheses to a body using everyday materials.
3. Remind students that when engineers design a new or improved product, they work in groups and follow the steps of the *engineering design process*:

   1) understand the problem or need
   2) come up with creative ideas
   3) select the most promising idea
   4) communicate and make a plan to describe the idea
   5) create or build a prototype or model of the design
   6) evaluate and refine what has made.

Week Three - During this week, the students will start thinking about the structure and function of the engineering design of their own Prosthetics model. Students will conduct background research, collect materials needed to build their model.

Materials needed

- Prosthetic activity sheet (Appendix)
- Images of Example Prototype Prostheses
- 1 roll duct tape
- A yardstick, ruler or tape measure, for measuring
- Scissors
- One type of prosthetic structural material with which to create a prototype
- Prosthetic Party Worksheet, one per person

Prosthetic Structure material suggestions include:

- (For leg structure): toilet plungers -unused, plastic pipes, metal pipes, metal strips, cardboard tube from wrapping paper roll, wooden “2 x 4,” thin metal duct material to be rolled and taped into a tube shape, all generally 1.5 ft or .46 m. long
- (For comfort): Large sponges, scrap bubble wrap, scrap cardboard, etc.
- (For lifelikeness): bath towels, pairs of pants, shoes — use students’
- (For body attachment): string, rope, twine, about 30 ft or 10 m

Activity

1. Divide the class into enough teams so each has a different structural prosthetic material.
2. Assign teams different material resources with which to construct their prostheses. Make available other materials for them to consider incorporating into their design.
3. Hand out prosthetic worksheet and have students follow along with the questions throughout the activity.
4. Have students discuss ideas within their groups, while completing the first page of the worksheet.
5. Have each group choose one teammate for whom to make the prosthesis. Measure his/her lower leg from where it bends at the knee, to be sure the prosthesis fits.
6. Have students collect other materials, such as tape and string, and begin creating their prototypes, creatively addressing the requirements of strength, stability, durability, longevity, shock absorption, lifelikeness, comfort, etc.

Week Four - During this week, the students will build their Prosthetics model and prepare to demonstrate it to their peers.

Post activity reflection

1. After all teams are finished, each group will present their prosthesis to the rest of the class, explaining their design concepts and choice of materials, as well as demonstrating the prototype's strength by having their teammate use it to walk. Give the teams in-class and homework time to prepare their presentation.
2. When the groups present, they can imagine they are doing so at an engineering conference. They should include in their presentation:
    a. List of materials and purpose of each
    b. How they came up with the design
    c. Important design features
    d. Estimated cost
    e. Demonstration of use
3. Be sure to allow time for students to ask questions and to evaluate the other groups' presentations. What solutions did groups devise that were particularly clever? What problems did all the groups encounter?
4. Reflection questions for students
    a. What improvements could be made to your prototype?
    b. What other materials would help improve your design?
    c. What would be different if you had to make the whole leg, including the knee?
    d. What design constraints or limitations might be different for biomedical engineers developing real prostheses?

Resources Appendix

Works Cited

Bellman, R., Holgate, M. and Sugar, T. (2018). *SPARKy 3: Design of an active robotic ankle prosthesis with two actuated degrees of freedom using regenerative kinetics*.

Biomedical Engineering and the Human Body. (2018). [Blog] *Hands-on Activity: Prosthetic Party : Build and Test Replacement Legs*. Available at: https://www.teachengineering.org/activities/view/cub_biomed_lesson01_activity1 [Accessed 26 Jun. 2018].

Dellon, B., & Matsuoka. Y. (2007). Prosthetics, exoskeletons, and rehabilitation [Grand

Challenges of Robotics]. *IEEE Robotics & Automation Magazine*, *14*, 30-34.

Doi.org. (2018). *SmartLeg: An intelligent active robotic prosthesis for lower-limb amputees - IEEE Conference Publication*. [online] Available at: https://doi.org/10.1109/ICAT.2011.6102090 [Accessed 25 Jun. 2018].

Osborn, L., Dragomir, A., Betthauser, J., Hunt, C., Nguyen, H., Kaliki, R. and Thakor, N. (2018). *Prosthesis with neuromorphic multilayered e-dermis perceives touch and pain*.

Robert Bogue, (2009) "Exoskeletons and robotic prosthetics: a review of recent developments", Industrial Robot: An International Journal, Vol. 36 Issue: 5, pp.421-427, https://doi.org/10.1108/01439910910980141

Standards

NGSS: Next Generation Science Standards - Science

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts

HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

Pennsylvania State Science Standards

BIO.A.1.2.2. Describe the interpret relationships between structure and function at various levels of biological organization (i.e., organelles, cells, tissues, organs, organ systems, and multicellular organisms).

S11.A.1.1.4. Explain how specific scientific knowledge or technological design concepts solve practical problems

S11.C.3.1.2. Design or evaluate simple technological or natural systems that incorporate the principles of force and motion (e.g., simple machines, compound machines).

Teaching Materials - Prosthetic Activity

(Biomedical Engineering and the human body, 2018)

1. ***Plan*:** What characteristics, qualities and features will your prosthetic lower leg possess, and how will you provide these with the available materials?

Characteristics / Qualities	Plan

1. ***Measure:*** How long is the lower leg that is to be replaced by a prosthesis? ______________

2. ***Design*:** Draw a picture of how your prosthesis will look, using your plans from above. Label any measurement lengths or amount of materials to be used.

3. After creating your final design, list the materials you used and how they contribute to the function of the prosthesis.

Material	Function

4. ***Evaluate:*** While watching the group presentations, list the best feature of each group's prosthesis and what material or technique accomplished this feature.

Group	Best Feature	Material / Technique

5. From the group presentations, and reflection upon your own team's design, what improvements would you make to your prototype?

Teacher Materials - Prototype Prostheses Exemplars
(Biomedical Engineering and the human body, 2018)

Example 1: A pipe is chosen to provide structure. To provide some comfort for the knee, a piece of sponge is cut and taped to the top of the pipe. For stability, a student's shoe is taped to the other end of the pipe. The student's knee is taped to the prototype prosthesis, providing a connection to the body.

Example 2: A cardboard tube is used for flexibility and lifelikeness. A metal strip is run through it to provide structural support. To provide some comfort, folded cardboard is duct-taped to the top of the tube. A piece of rope is threaded through a hole in the metal, providing a way to connect the prosthesis to the body. Through a hole poked in the cardboard tube, a student's shoe is tied to the other end of the tube, providing stability. The rope ties the prosthesis to the student's knee, which rests on the cardboard tube. Even with a flimsy cardboard tube.

Example 3: For structure, a piece of open-sided, round duct was duct-taped into a tube shape. The knee end of the tube was closed using more duct tape and a piece of the metal duct material. Some comfort came from the tape and the air underneath it.

Lifelikeness: Wrapping a piece of wood with a towel can make the prosthesis appear and feel more lifelike, especially once covered by a pair of pants!

Comfort: Get creative to find different ways to make the prosthesis comfortable! (left to right) Perhaps a crumpled piece of paper taped to a copper pipe, a piece of bubble wrap taped to a piece of wood, or the rubber head of a toilet plunger.