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Advancing Prosthetics-Enhancing Comfort and Effectiveness for Amputee

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A B S T R A C T

The field of prosthetics technology has advanced significantly since its inception. Initially, prosthetics was simply intended to be aesthetically pleasing and functional. A period when prosthetics may fully replace a human limb's functioning is becoming possible thanks to advancements in the material sciences, engineering, and medicine. This review article explores more into the current strategies for implementation of prosthetics and the ways that have been developed to make life easier and comfortable for the amputee.

Introduction

Though several new developments are being made in the field of prosthetics, enhancing the quality and implementation to make the prosthesis the most effective for the amputee is still not given enough importance (Yu *et al.,* 2021). This review critically examined upper limb prosthesis acceptance and abandonment as documented from the last 25 years starting September 2007.

This article highlighted the rejection rates, factors associated with abandonment, patterns of wear and customer satisfaction. It states that though these developments have succeeded in this purpose of many clinical and consumer studies, many patterns observed regarding prosthetics usage show that amputees are still not satisfied with their prosthesis. The implementation of prosthetics is really important because it is personalized for every individual. Choosing the right method that will most effectively fix the issue. Because of residual limb characteristics might not be an appropriate candidate. There are some perceived limitations in the comfort or functioning of this technology. Lot of research reveals that many of the amputees who use prosthesis don't use it often and only for work and social activities (Yu *et al.,* 2021).

Aim of prosthetics is to restore as much function as that was lost during amputation and help the person use the prosthetic in the most natural and normal way possible (Tian *et al.,* 2019). The discomfort caused by neuroma and phantom limb pain after implementation of prostheses can be overcome by a surgical procedure called TMR (Targeted Muscle Reinnervation) which increases control signals for prosthetic control.

A myoelectrical signal is a signal that utilizes electricity generated by the muscle to control artificial limbs. It is typically associated with the contraction of muscle and is used for a TMR procedure.

This surgical procedure can be conducted while the amputation is being done or even during revision surgeries but if there are only very few residual muscles then this procedure can be carried out on trunk muscles as well (Azocar *et al.,* 2020).

The prosthetic that can be implemented depends on the type of amputation as well.

Level of amputation is characterized into mainly 5 different types:

- Partial foot or partial ankle amputation.
- Knee level amputation
- Below the knee or transtibial amputation
- Above the knee or transfemoral Amputation
- Hemipelvectomy or trans-pelvic amputation

During the implementation of prosthetics, this factor should be taken under consideration as well. Another reason why amputees abandon prosthesis is due to significant device weight. The MPL or Modular Prosthetic Limb system was developed at the John Hopkins University Applied Physics lab as part of the DARPA initiative. 17 independent motors increase user control over the actuating joints. It also has 360°/s joint speed, multi-articulating fingers, a four DOF thumb, finger spreading via abduction and adduction, joint sensors for position, velocity, and torque, integrated limb control system hardware and software, and a three DOF modular wrist (i.e. rotation, flexion/extension, and abduction/adduction) (Paysant *et al.,* 2006).

Since 2011, a study conducted in the University of Pittsburgh in Pennsylvania have been using neural implants to control prosthetic limbs. Electrode rays were implanted in the persons brain to read its neural activity and to control a robotic prosthetic and deliver a sensation when something is touched. This attracted a lot of attention to the US Food and drug administration department (FDA) as they were concerned if this method was safe. These scientists brought to the spotlight many challenges that the device might bring if it malfunctions or how such long electrodes can stay in the brain, if this device is brought to market (Loucas *et al.,* 2017).

Skin interfaced devices will also make prosthetics more wearable for the amputee. They have demonstrated the use of large area interfaces for multifunctional control of transhumeral prosthesis who have already undergone a TMR (Dong *et al.,* 2020).

Although results with TMR have been very promising, the TMR procedure can only acquire a single independent EMG signal for each nerve transfer. Ideally two EMG signals need to be acquired in order to control each degree of freedom in the TMR process. One being opening and closing of the hand and second, elbow extension and wrist flexion. Refinements done to the TMR procedure would lead to creation of more independent EMG signals. A surface EMG can also be looked at as a solution however accessing EMG signals from deeper muscle regions remains a challenge (Onwuasoigwe *et al.,* 2021). IMES (Implanted myoelectric sensor system) would eliminate problems like signal attenuation by subcutaneous fat, cross talk, movement artifact, and skin impedance variation. It would bypass the skin interface, provide access to deeper tissues, and allow recording from more focal areas of target muscle (Azocar *et al.,* 2020).

Prosthetic limb control strategies are still not widely known, especially when the safety prospect is taken into consideration. Many people with limb amputations experience a lower quality of life due to the significant mobility challenges that they incur on a day to day basis. Although passive prosthesis solves the mobility aspect of their condition, the other physical, psychological, and social impacts remain rigid and unchanged.

AI has created such a wonderful impact in the field of prosthetics and rehabilitation. In my opinion, it enables two things, preciseness and adaptability. An appropriate example to support this claim is the use of a smart socket. This device if integrated into a prosthetic has sensors that detect and check volume changes in the residual limb and automatically adjusts the prosthetic so as to ensure a perfect, comfortable fit (Azocar *et al.,* 2018). The Open source leg was made with the intention to give high performance while trying its best to minimize mass and cost. Each and every element used has been chosen such that this prosthetic weights lesser than an actual limb and cost lesser compared to other conventional prosthetics. Low transmission ratios (target ratio for OSL is 49:1) are important in a bionic leg as they improve efficiency, bandwidth, size and electric commands. Thus, brushless electric motors have been fitted at each joint. These motors were initially built with the purpose of being used in the drone industry which meant that it offered high torque and high motor constant. Benchtop testing which included electromechanical and thermal performance testing was done to ensure success of the prototype (Blatchford, 2021).

Figure.1

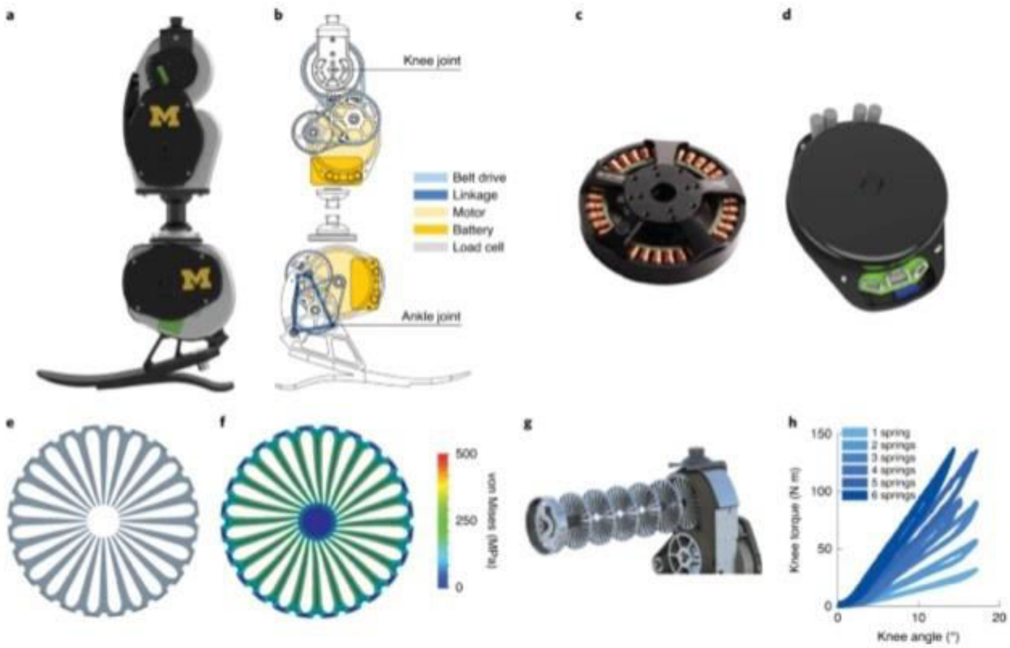


Figure.2

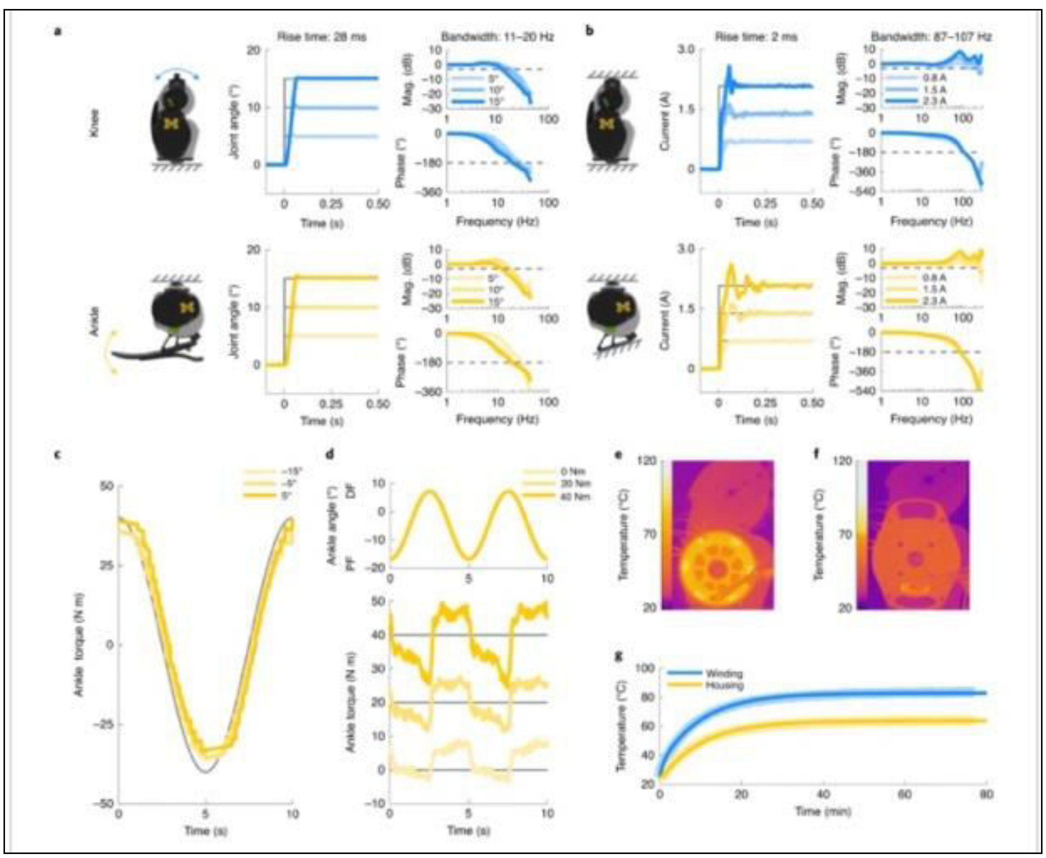
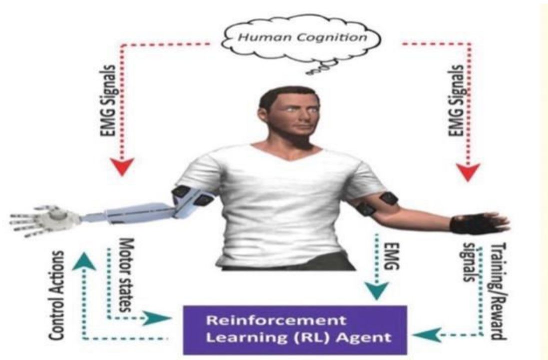


Figure.3



Clinical testing was also done to emphasize on its kinematic and kinetic abilities in the real world. After several tests on three amputees, they approved of the prosthetic as being "supportive, responsive and smooth". This kinematic test was conducted five ambulation modes namely, Knee angle, knee torque, ankle angle, ankle torque and vertical GRF (Ottobock, 2021). Machine learning namely supervised, unsupervised and RL (reinforcement learning) have a huge influence on prosthetic technology. Supervised learning is applied when using a range of inputs to discover a certain pattern or trend and make a prediction or claim based on the raw information collected. Reinforcement learning refers to learning from past mistakes to determine a better solution or action from a trial and error method. Maximizing the reward based on previous results is what this focuses on and exactly what keeps the adaptability aspect as the main highlight. The figure below shows how reinforcement learning aids in the functioning of a bento arm (Natalie *et al.,* 2021).

For instance, the activities of the EMG signal provide visual feedback to the prosthetist and amputee. The prosthetist discovers a new site of electrode in the residual limb until optimization is achieved such that the results cannot be maximized further. To enhance the comfort of a myoelectric prosthetic hand, a sensory feedback device was created. This device allowed force sense feedback and temperature sense feedback. The temperature sense element was tested by Mormitzu and Katsura who analyzed the temperature transfer using a Peltier element.

Otzura *et al.,* also created a device that detects temperature and tested it using a hot and cold pad. This meant that the prosthetic hand was not merely a biomimetic prosthetic that restored physical function, but it also restored near natural function (Hisano *et al.,* 2021).

To increase the sense of touch, a FFB device was developed with a safety mechanism. This device comprised of a belt with a motor that recognized the hardness of the object being touched and expressed it to the amputee. Shortly after experiments were conducted, to test and distinguish five different kinds of spring which it was successfully able to accomplish (Natalie *et al.,* 2021). Similarly to increase recognition of change in temperature a TFB device was developed. This would present temperature of an object when amputee touched it with the prosthetic arm. In addition, to recheck, a series of experiments were held to distinguish among five different temperatures (Horne and Neil, 2009).

Enhancing sensory feedback in prosthetics has a massive scope for research. This could mean enhancing user environment by improving proprioception, sense of touch or even temperature. Prosthetics can also be customized according to the user in many ways in terms of its design although significant progress has been made to this aspect. WHO (World Health Organization) declared that 35-40 million people require prosthetic or orthotic devices but 75% do not have this due to poor clinical coverage. When a huge amount of money is being used to create such technology, it is highly important that we tackle the problem of affordability so that more amputees are willing to use prosthetics and thereby radically change their lives with such revolutionary technology.

Author Contribution

Keerthana Biju: Investigation, formal analysis, writing—original draft. Ambili Mechoor: Validation, methodology, writing—reviewing. Rahna K. Rathnan:—

Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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