The 2nd International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/4/20220686

A Future Realistic Model of Bionic Limbs with High Accuracy

Qianyu Zhao

Department of Electronic Engineering, School of Integrated Circuits and Electronics, Beijing Institute of Technology, Beijing 100081, China

zhaoqianyu200201@163.com

Abstract. Bionic limb achievements in the last 10 years have primarily focused on breakthroughs to improve accuracy with new materials and concepts that are unlikely to be used when producing an entire upper bionic limb. For example, studies on bionic limbs with new materials, such as pneumatic bionic flexible arms, which cannot meet the needs of amputees in terms of using comfortably and accurately interpreting users' intentions. Though the future development of bionic limbs has many possibilities, this paper summarizes and analyzes the functions and drawbacks of three most important structures in bionic hands and compares them to the most widely used sensory feedback realization methods. The paper then designed a future model based on the perspectives discussed above in order to meet the requirements of high accuracy, flexibility, a comfortable feeling, and real-time sensory feedback. Finally, the paper contrasts the BCI technique with the newly developed model.

Keywords: future model, high accuracy, comfortable, user-friendly, bionic limbs.

1. Introduction

The achievements of bionic limbs in the last 10 years have primarily focused on breakthroughs to improve accuracy with new materials and concepts that are unlikely to be used in the production of entire upper bionic limbs. For example, studies on bionic limbs with new materials, such as pneumatic bionic flexible arms, which cannot meet the needs of amputees in terms of using comfortably and accurately interpreting users' intentions. This paper summarizes some perspectives derived from researchers with backgrounds in electronic science and biomedical engineering through a review of the literature. The most important aspect of this passage is the development of a future model for bionic upper limbs used by amputees. Furthermore, this paper suggests a possible model that can be used to produce highly realistic, reliable, and comfortable experiences via future bionic upper limbs for amputees in order to address the issue that scientific research results have difficulty translating into practical commercial products. This model depicts a promising future for amputees.

2. Summary Of Tranditional Structure

The typical structure of bionic limbs is known to be divided into motor, actuator, and sensor. Direct current motors are commonly used in upper bionic limbs. Upper bionic limbs that have advanced in mimicking nerve fiber or muclse functions, as well as shape and structure, will be pursued in the future. As a result, greater motor accuracy will be required. On the other hand, for cutting-edge designed bionic

DOI: 10.54254/2753-8818/4/20220686

upper limbs, the idea of controlling actuators through current or voltage based on actuator characteristics may result in a lack of accuracy [1].

Because tactile sense is the primary sensory feedback of human upper limbs, piezoelectric sensors are the most commonly used. Recently, a soft sheilded sensor was developed that can achieve high accuracy in soft sensors and can be applied to next-generation bionic upper limbs [2]. As a result, soft bionic upper limbs equipped with soft piezoelectric sensors to improve flexibility, comfort, and accuracy are likely in the near future. In most cases, high temperature resistance materials resulted in bionic upper limbs lacking temperature sensors, leaving amputees with no real hand perception [3]. However, in the future, researchers should try to reduce the pain of amputees caused by imbalances in both sides' senses, which means multiple sensors located in at least main functional areas mimicking those of real hands are required.

For actuators, which are more important than other structures in terms of flexibility. Many significant bionic limb outcomes have recently used the pneumatic actuator [4]. However, it will not be the future treatment devices. Pneumatic actuators, on the other hand, are typically designed for specific tasks such as mechanical arms in a factory or operating room [5]. The most promising future actuators for amputees may not rely on the development of new materials such as memory metal or other new material fibers that require tiny simulation that is difficult to control [6]. However, the structure of bionic limbs should resemble that of real human hands, allowing artificial upper limbs to perform tasks in the same way that real hands do. Thus, the materials used to construct the hand skeleton must meet the characteristics of human bones and joints, including qualified mechanical properties, friction and wear properties, biochemically stable performance, and appropriate weight and cost.

3. Sensory Feedback

Another major issue is the sensory feedback system. Nowadays, the most common realization method is to implant sensors in bionic limbs to measure joint position, touching pressure, and grasping strength, and to stimulate the remaining body parts to transfer sensory information to the user. The touch of real human fingers is closer with a liquid sensor developed by Florida Atlantic University, but the current sensor area is small and does not achieve a large-area perceptible function similar to the natural human hand [7]. However, new material sensors should ensure multiple and large area coverage sensing in the future to achieve as much as real human hands to reduce the pain of losing a hand and the discomfort of mechanical alternatives.

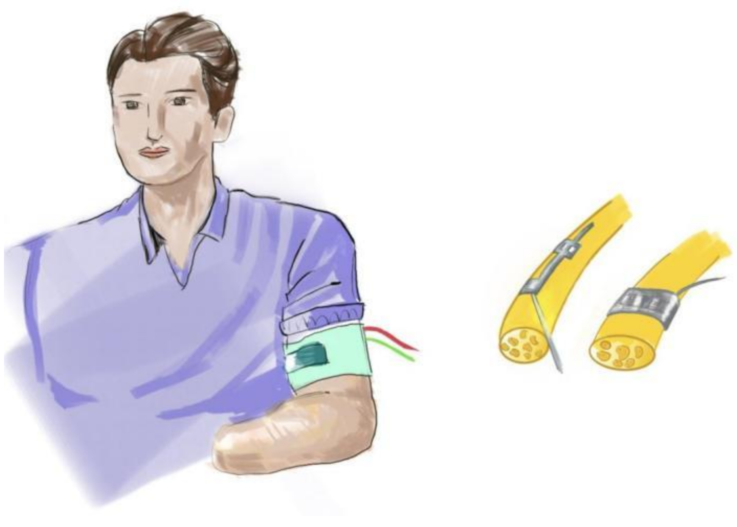

Figure 1. Implanted and non-implanted feedback sensors [8]

In terms of the stimulation process, there are currently two options for stimulating the skin of residual limbs: non-implanted and implanted. The non-implantable sensory feedback method involves stimulating the skin of the residual limb to restore prosthetic sensation. Mechanical and electrical stimulation methods are currently available. Mechanical approaches to haptic receptor stimulation include the use of vibrating motors, linear pushers, skin stretchers, or pressure cuffs [9]. Delivering low-intensity current pulses through surface electrodes to activate cutaneous afferent nerves or to induce transcutaneous electrical nerve stimulation, as well as implanted microelectrodes to electrically stimulate peripheral nerves, are examples of electrical methods [10]. A time-varying stimulation pattern communicates the prosthesis state to the user. The frequency or intensity of electrotactile or vibrotactile stimulation, for example, can be modulated proportionally to the measured grasping force. These methods can provide various perspectives on natural perceptual pathways [11]. Because direct nerve stimulation can activate the same natural neural pathways that transmit sensory information, adapting direct stimulation with implanted electrodes to provide natural sensory feedback may be more effective than non-invasive methods [12]. In the future, implanted electrodes should have low electrical impedance, flexibility, and mechanical stability, as well as a large charge storage and injection capacity to provide a long-term stable working state, ensuring amputees a more accurate, safe, and comfortable experience.

4. Algorithm Comparison

In addition, the method of training sensory feedback varies. Supervised learning, unsupervised learning, and deep learning are the most commonly used methods. Machine learning includes both supervised and unsupervised learning.

4.1. Unsupervised learning

In contrast to supervised learning, which predicts the model within the trained input learning function to map the known set output and then determines the pattern of the new dataset, the unsupervised learning algorithm finds a solution to unknown or unlabeled data with no human supervision [13]. Thus, there were already applications in bionic knees where an unsupervised learning algorithm realized the intent detection function with unlabeled data based on a known pattern. If it is to be applied to the upper limbs, the algorithm must ensure the accuracy and stability of working processes while dealing with a more complicated intent possibility.

4.2. Reinforcement learning

Another algorithm will be used to better mimic the real upper limbs because feedback from the environment and past behavior will be taken into account, which means that the agent learns from the consequences of its actions and the next choices are based on past experiences and trial and error learning. Agent and environment are the components of reinforcement learning.

For example, the strategy used to determine the next choice in the RL method includes a variety of learning methods. A sequence of state-action pairs is recorded during the demonstration and used to train the prosthesis. The training limb was the intact limb, and the contrast limb was the amputated side prosthesis. The agent, learner, or amputee is asked to perform the same movement on both limbs during training, and the information from the trained limb is used to create a prosthetic strategy to map the action state of the contrast limb. The opening of the prosthesis may not be the same as the training limb during initial training, but when training occurs before the hand gradually opens as a reward to the agent for acquiring the appropriate movement and position to open the desired prosthesis for graded grasping. Hand prosthesis and proportional controls Another example of comprehending exploration and development strategies is determining the precise location of surface electrodes in an amputee's stump. It is a trial-and-error procedure that involves placing surface electrodes in various locations around the amputee's stump in order to obtain the action potentials required to operate the prosthetic hand [13].

4.3. Deep learning

Deep learning is another method that combines supervised, unsupervised, and a subset of machine learning and AI. This method has the advantage of being inspired by the human brain neural network system regardless of whether the human brain network is plastic or analog. As a result, it can learn and

DOI: 10.54254/2753-8818/4/20220686

remember generalized and prompted models of biological neural systems. As a result, this method is more effective at solving pattern recognition and matching, clustering, and classification problems. Deep learning models produce results faster than other standard machine learning solutions. BCI controlling prosthetic arms via EEG-based pattern recognition is a common example of deep learning in bionic limb fields [13].

As for other AI methods, it include reasoning, knowledge representation, planning, learning, natural language processing, perception, object movement and manipulation, and many more [13].

5. Future Model

Based on the information presented above, the paper created a model of a possible future bionic limb that adheres to the principle of mimicking the function and operation of a real hand and designing the bionic upper limbs with sophisticated materials and structures such as liquid sensors. Because of the ever-increasing demand for high accuracy, flexibility, comfort, and real-time sensory feedback, the bionic hand must be trained using AI techniques such as reinforcement learning, deep learning, or other AI techniques. Figure 2 depicts the design process created with Biorender.com.

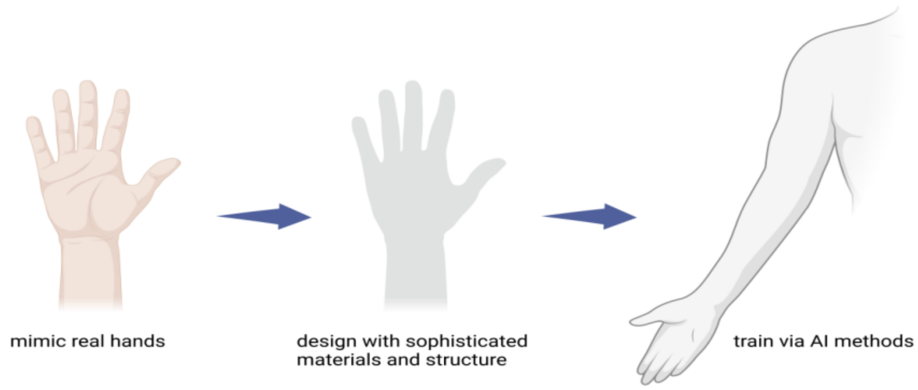

Figure 2. Basic design steps and demands of future bionic limbs (original)

In the Biorender.com model of future bionic upper limbs shown in Figure 3, feedback sensors with soft material to achieve high accuracy are equipped on each finger position to realize touch sensory feedback like a real hand. Furthermore, the skeleton structure mimics the function of the human skeleton structure by adding reinforcement material at vulnerable points to improve durability. Furthermore, various sensors to detect temperature and gain touching feeling will be added to the palm of hands to mimic the real feelings of human hands. Because of mechanical process differences, the entire area on the back of the hands should be covered by sensory materials, whereas only dots-like sensors are equipped in the palm area. Finally, the model must be trained using an AI algorithm, specifically Deep Learning and Reinforcement Learning methods, to achieve breakthrough in highly sensory feedback functions. In the future, interfacing devices as small as peas could be implanted at the appropriate position of residual parts as well as bionic limbs. Wireless transmission between bionic limb terminals and residual parts will be possible in the future.

DOI: 10.54254/2753-8818/4/20220686

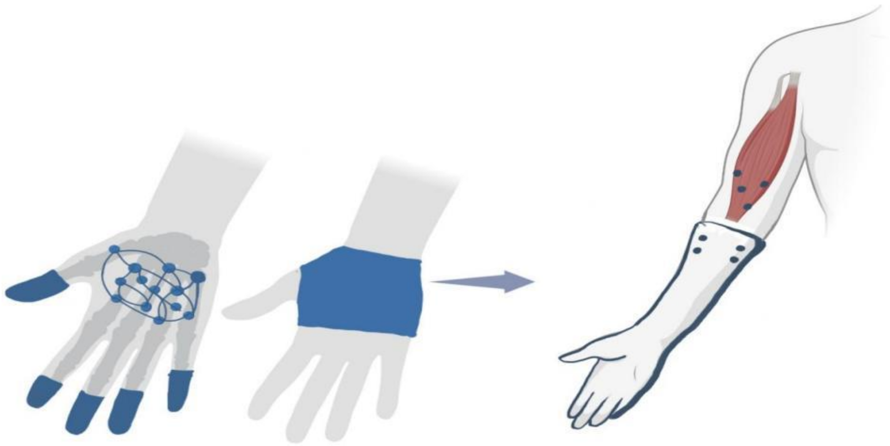

Figure 3. Design of future bionic limbs (original)

Last but not least, at this time, the BCI method for solving sensory feedback and signal sent out capturing process is harmful to amputees due to the risk of surgery, implant infection, and functional impairment of the brain. As a result, only if the implant is designed as small as a chip with no large rejection reactions and low infection risk, and the surgery is minimally invasive, will BCI be a better choice for consumers than the model designed above.

6. Conclusion

This paper summarized and analyzed the functions and drawbacks of three of the most important bionic hand structures, as well as compared them to the most widely used sensory feedback realization methods. The passage then designed a future model to meet the requirements of high accuracy, flexibility, comfortable feeling, and real-time sensory feedback, based on the perspectives discussed above. Finally, contrast the BCI technique with the newly developed model.

The references in this paper may be a little limited, which may result in a lack of recognition in the commercial field of bionic limbs and unprofessional terminology appearing in the passage. However, as more knowledge in bionic limbs and experiments based on this model is accumulated, the model can be modified. Furthermore, the comparison within different algorithms is theoretically limited, so in the coming months, comparisons based on specific cases will be carried out to test my conclusion.

References

[1] Gu, G., Zhang, N., Xu, H. et al. A soft neuroprosthetic hand providing simultaneous myoelectric control and tactile feedback. Nat Biomed Eng (2021).

[2] Aksoy, B., Hao, Y., Grasso, G. et al. Shielded soft force sensors. Nat Commun 13, 4649 (2022). https://doi.org/10.1038/s41467-022-32391-0

[3] Makin, T., de Vignemont, F. & Faisal, A. Neurocognitive barriers to the embodiment of technology. Nat Biomed Eng 1, 0014 (2017).

[4] Nguyen, P.H., Zhang, W. Design and Computational Modeling of Fabric Soft Pneumatic Actuators for Wearable Assistive Devices. Sci Rep 10, 9638 (2020).

[5] Wang, Y., Xu, Q. Design and testing of a soft parallel robot based on pneumatic artificial muscles for wrist rehabilitation. Sci Rep 11, 1273 (2021).

[6] Shen, Q., Trabia, S., Stalbaum, T. et al. A multiple-shape memory polymer-metal composite actuator capable of programmable control, creating complex 3D motion of bending, twisting, and oscillation. Sci Rep 6, 24462 (2016).

[7] Abd, M.A., Paul, R., Aravelli, A., Bai, O., Lagos, L., Lin, M. and Engeberg, E.D., 2021. Hierarchical tactile sensation integration from prosthetic fingertips enables multi-texture surface recognition. Sensors, 21(13), p.4324.

DOI: 10.54254/2753-8818/4/20220686

[8] Nerve implant for stimulating afferent fibres to restore sensation https://doi.org/10.1038/s41551-021-00732-x
[9] Farina, D., Vujaklija, I., Brånemark, R. et al. Toward higher-performance bionic limbs for wider clinical use. Nat Biomed Eng (2021).
[10] Farina, D., Vujaklija, I., Brånemark, R. et al. Toward higher-performance bionic limbs for wider clinical use. Nat Biomed Eng (2021).
[11] Bensmaia, S.J., Tyler, D.J. & Micera, S. Restoration of sensory information via bionic hands. Nat Biomed Eng (2020).
[12] Bensmaia, S.J., Tyler, D.J. & Micera, S. Restoration of sensory information via bionic hands. Nat Biomed Eng (2020).
[13] Nayak, S. and Das, R.K., 2020. Application of artificial intelligence (AI) in prosthetic and orthotic rehabilitation. In Service Robotics. IntechOpen.