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REVIEW ON RECENT ADVANCEMENTS IN BIONICARM

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Abstract—**Bionic arm has been a prime example of bending technology to improve the lives of amputees. This paper aims to study bionic arm and its developments through the years. The paper primarily focuses on the 'mechanical-human spectrum' and its implications on the feasibility of the arm. This paper also highlights the various actuation systems used in practice which are a key component of the arm. When feedback is provided to any system its performance is enhanced, this is also true in case of the arm and the paper describes all aspects related to it.**

Index Terms— **Bionic arm, Actuation systems, Feedback systems**.

I. INTRODUCTION

The motto of new era in medical sciences is, "**Repair it if you can, Replace it if you can't"**. Replacing a hand, is a daunting task it really shows how complex human body is. People have been trying to find a substitute for the lost body part by replacing them with various artificial objects. Bionic arm is a revolutionary idea for amputees across the globe. This is as close as we can get to our natural limb. The fundamental point is to make the arm move with our brain unlike previous prosthetic upper limbs.

In the case of bionic arm, we take the nerve conduction signals from the brain or muscles and amplify it so that we can register the signal and convert that electrical signal into mechanical energy so as to move the mechanical device i.e. the arm. Prosthesis is being used and constantly being perfected to suit human needs. Various types of prosthesis have been made to suit many actions but not all. But the bionic arm will be able to perform all kinds of movements of the human upper limb even the most difficult actions like unscrewing the cap of bottle or picking up a coin from the ground. Such developments in technology will help us to make the bionic arm function more like an actual human arm [1]. Bionic arm is not yet popular due to its cost and availability, but it has potential to change the lives of amputees. The medical and the engineering people should research on making this version of bionic arm better and efficient in order to make it impersonate the movements of the natural arm.

Patients usually desire a more natural appearing artificial hand rather than a hook, but functionally, such hands are less than ideal; they are heavy and not waterproof, and the skin-like gloves placed over them are not sufficiently durable for sustained use. [2]Development of actuators and sensors has been gaining pace, thus we are able to closely mimic the human arm. To have a highly accessible bionic arm all the above factors have to be considered. Furthermore, this paper critically analyses these factors and links them with the bionic arms available under research.

The primary function of the bionic arm is to replicate the human arm, thus measuring the 'closeness' towards a more human like arm is an important factor. This can be expressed by the 'mechanical-human spectrum' which is shown below:

The spectrum can be used to convey that any system/machine is depicted on either the data derived or data centric side and it enables to plot it on the spectrum; the same is true for the bionic arm. The earliest of bionic arms were machine centric and had very to no human characteristics to it, also they were out of tune with rest of the human body. Due to this nature many were not able to consider it as a part of their body. After technological advancements, researchers were able to bridge the gap between the human and bionic arm. This gave a sense of

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belonging to the amputees as the arm was responsive and natural in its movement.

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II. COMPONENTS OF BIONIC ARM

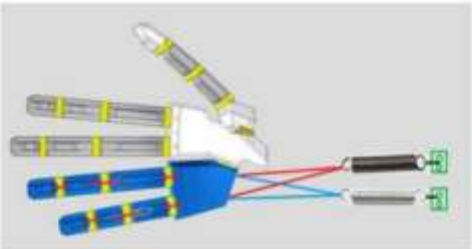
Actuation systems

Robotics has often looked biological muscle tissue as a performance standard for developing new artificial muscle actuators. Biological muscles, specifically skeletal muscles, exhibit remarkable capabilities that make them a unique and desirable actuator. They have the following properties. 1) A high power-to-weight ratio. 2) Inherent compliance and damping. 3) Achieve fast controllable actions. 4) High dynamic range. [3]

Erkan Kaplanoglu [4] (2012) gave an interesting method of actuating prosthetic hands is by using shape memory alloys (SMA's). SMA's return to a predefined shape or size when subjected to the appropriate thermal procedure (heating or cooling).The design shown further from Vanderbilt University uses SMA springs which contract when heated during passage the electric current through it, resulting in closing of fingers due to tension in tendons. There are two disadvantages associated with this:

- Due to factors like-SMA contraction rate, spring response and varying weights of the objects, developing a precise control system for SMA actuators becomes very complex.
- Heating the SMA and then waiting for it to cool can take lot of time which makes closing and opening a finger a relatively slow process.

As this technology is developed further SMA's may become an effective actuation option for artificial hands. A big advantage is that they are noise free and light weight.



Liangjian Zhonget al[5] (2019) demonstrated method of actuation which has gradually gained attention in recent years and has been extensively investigated in the fields of biomimetic technology, collaborative robots due to their lightweight, strong output power, and inherent safety. PAM (Pneumatic artificial muscles) is a tensile actuator that mimics the natural movement of the human muscles. It consists of a tube and connectors. The tube is made up of a rubber diaphragm with a non-crimped fiber made of aramid yarns on the inside. When the pressure inside the tube increases, the tube is pushed outwards. The diameter of the tube increases, whereas the length of the tube shrinks. As a result, the PAM get contracted, generating pulling actuation. When the pressure of the tube decreases to the ambient pressure, under the action of the external woven mesh, the PAM gradually recovers to its initial state. The experimental results show that the swing angles of the two arms can follow the desired trajectory very well. The tracking errors of the upper and lower arms are within 0.25° and 0.3° and the motion accuracy of PAM is significantly affected by hysteresis effect.

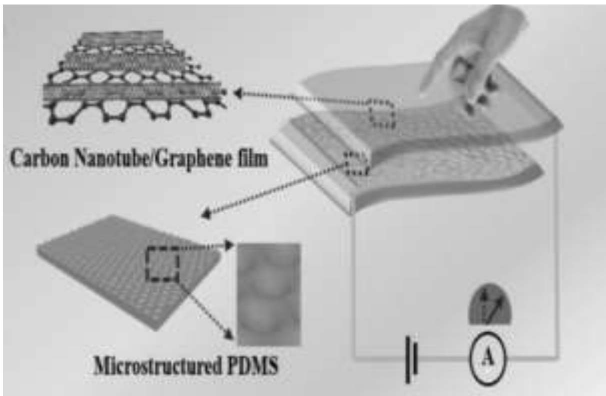
Michael C. Yip et. al[3](2017) studied that by continually twisting polymer threads to an extreme until they form coils, an actuator is achieved with a power-per-weight, strain, and deformation rivalling or even exceeding that of human skeletal muscle, whilst keeping a rope-like form factor. These "super-coiled polymer" (SCP) actuators were originally produced using carbon nanotube polymer yarns that were twisted until coils were formed and are capable of being activated electrically, chemically, and photonically. They were able to produce tensile actuations (strain) of up to 8%. The same effect can be achieved by using commercially available fishing lines and sewing threads by heating and cooling the coiled actuators. SCP threads thus can produce significant mechanical power in a desirable form factor, and are easy to manufacture and extremely cost effective. The great benefit of SCP actuators are they have accurate control, inherent compliance and damping, fast activation. And these characteristics of SCP actuator are well matched to the needs of artificial muscles.

Many low-cost bionic arms use artificial tendons as another viable way of actuating bionic hands. The tendons can be any high strength line which must be stiff to achieve full movement of fingers. The overall weight is reduced as they can be actuated with very few actuators. Tendon mechanism of the human hand is replicated with it. These tendons connect to the fingers and are tensioned by motors in the forearm. Pulling on the tendons cause the fingers to open and close. The electric motors driving these tendons must be completely housed inside the device in order to make it portable and attachable to an amputee. Due to their relatively large size of motors we cannot house the motors used inside the palm section. Instead the motors are housed within the forearm. Considering all the above advantages it is one of the best effective actuation system available.

Feedback systems

In order to make the bionic arm more naturalit is paired with a proper feedback system, which gives accurate data about the position of the fingers additionally, sensors that provide haptic feedback commonly known as the 'sense of touch'. Apart from just haptic feedback, sensors are necessary to interchange data with the controller and change the position of the fingers according. These sensors when aligned in accordance with the motors and EMG sensor make up the feedback system. Following are few feedback systems that are being used in various prosthetic devices.

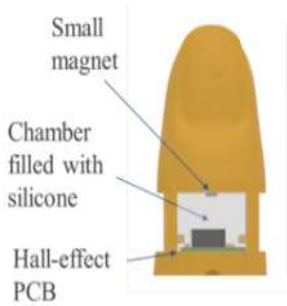
Muqiang Jian et al[6](2017) describes a flexible and highly sensitive pressure sensor based on biomimetic hierarchical structures and highly conductive active membranes. Due to the unique hierarchical structures of both the ACNT/G (Aligned carbon nanotubes/graphene) and m-PDMS (micro structured polydimethy lsiloxane) films, the obtained pressure sensors demonstrate high sensitivity, fast response time, low operating voltage and excellent stability. Force/pressure sensors are generally used on the fingertips which provide the force data to the controller. Force sensors gives us the amount of force that is been applied on the sensor by any object. This force value can help the arm to manipulate the amount of force the fingers exert on the object in order to hold it. This means that the arm can vary how tight or loose it must hold the object in order to accomplish the task and not let the object fall off as a result of some unbalanced force.



Joga Dharma Setiawan et al[7](2020) proposed a data- driven control method of extra robotic fingers to assist a user in bimanual object manipulation that requires two hands while the postures where driven by the flex sensors and where further used to drive the neural network. As the name suggests this sensor give the data about flexion or bending of the fingers. These sensors can provide feedback for trained objects and help the arm to grip more effectively.

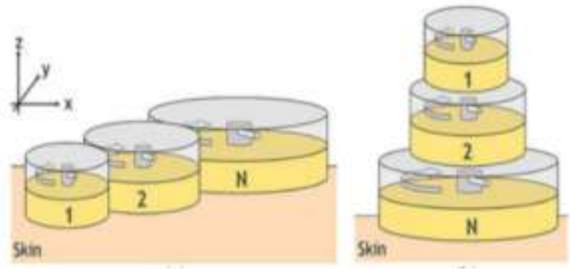
S. Said et al[8](2020) developed a neural network which took input from the my ware and extracted specific features from the signal after pre-processing the raw EMG data were collected for a set of four gestures (fist, spread fingers, wave-in, wave-out) from a wide range of participants. Based on a pre-selected optimization algorithm, the classifier is trained to learn and identify patterns in the data and to respond to the inputs according to the given outputs. For this the SVM (support vector machine) multi class classifier was implemented to gain excellent performance for large number of features. After successful training, the reliability of the classifier is tested with a different dataset. The accuracy reached 90% which allowed the user more control over his bionic arm. Though it has the highest accuracy among all the feedback systems the overall cost is increased as a high-end microprocessor is required for the neural network.

Ann Marie Votta et.al[9] (2019) developed a 3D force sensing unit for both shear and normal force readings. In the standard force sensor normal force is measured to control grasp force, but in this 3D force sensor the shear force is also measured to ensure grasp stability. This helps in identifying when an object is lifted or if it slips. This can in turn help reduce the burden on the amputee, who now does not need to actively think about maintaining their grasp on an object. At the bottom of the cavity, attached to the bottom portion of the finger, is a PCB with a 3-axis Hall-effect sensor. At the top of the cavity, attached to the top portion of the finger, is a small magnet.



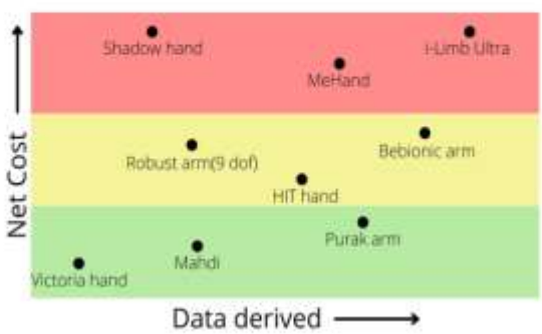
During grasping, if the finger contacts an object anywhere on the fingertip above the sensor, the top of the fingertip is deformed in some direction relative to the bottom of the finger, moving the magnet relative to the Hall-effect sensor. This results in a shear or normal force reading, depending on the direction of applied force.The positive x (normal) direction, then the negative y (shear during a side grasp), and finally negative z (shear during a top grasp) readings can be obtained. When the fingertip is pushed in a given direction, the magnetic field on that axis changes the most significantly. Due to this multi dimension nature of the sensor, intelligent grasping capabilities of the system can be unlocked.

Christian Cipriani etal[10](2011) presented a vibrotactile substitution system based on low power and cost miniaturized vibration motors. The miniature motors were controlled through a MOSFET used as a switch and was driven using a pulse-width modulation (PWM). Results were based on three different methods of discrimination and were calculated through six different grasps by an artificial prosthesis. The study claims that subjects were able to discriminate (75%) among the three amplitudes that were generated on the stumps through constructive interferences. The main drawback of this type of system is the time required to reach steady state of desired simulation is more (350-450 ms).



III. STUDY

From the above feedback and actuation systems, the arms under development are classified based on the concept of 'Mechanical-human spectrum' with the help of the following graph:



The graph clearly depicts how various existing bionic arms stand on the basis of their net cost and how close they are to an actual human arm which follows a data driven approach. I-Limb Ultra is observed as the costliest arm with also being highly data derived. Whereas, on the other end of the spectrum lies the Victoria hand which is quite affordable but very less data derived. It is worth noting that the Bebionic arm is not very different than i-Limb Ultra in terms of data derived nature yet it is significantly cheaper than the other. The Mahdi arm is a research based arm which is trying to push boundaries to make the arm more cost effective. Other such notable mentions include Bionic hand by Will Cogley, Vanderbilt hand etc. The efforts to make the bionic arms more affordable and natural are increasing every day. Below we will take a detailed look at some of the research based bionic arms.

Will Cogley[11] presented a project which aimed to design and build a bionic hand that mimics a real person's movement much closer than most current bionic hands in construction. When most artificial limb designs are usually blocked by my electric restrictions technology, this project was developed next to the wearable glove to receive good movement in the hand of the wearer and serve as a controller. In this way, the bionic hand was be able to quickly and accurately imitate the movements of the user's hand. This project hand has approximately 22 DoF's which makes its movement very natural.

The bionic arm design presented by Mahdi Elsayed Hussein [12] in his thesis project has an impressively low cost of about 250USD weighing 950 grams. The paper talks about a cheap 3D printed bionic arm with 4 grip patterns to perform basic tasks. It also suggest the various improvements that can be made to the model for increasing its functionality. Apart from this the presented arm also has high Finger actuation speed which is quite close to the actual human hand.

Open bionics' arm[13] is another open source bionic arm which is used as a base for many project and research activities. It has the standard DoF value of 5. "Hero arm" developed by Open bionics is by far the cheapest possible in-market prosthesis starting from just 3000USD.

Open bionics is on a mission to develop affordable bionic arms to help as many people as possible. Another model namely "Brunel hand" showcased a variety of gripping patterns for various objects with very fluid and natural movements. Many enthusiasts have used this hand model as the basis of their research due to its simple design and affordability.

The Victoria hand project [14] has a slightly different approach towards developing prosthetic limbs. This arm does not have any sensors, actuators or any other electronics. It is an arm which one adjusts with the help of their other hand. This type of arms are also called passive bionic arms. It not only helps reduce the cost of the arm but also reduces its weight significantly. This particular arm has a 360 degrees rotatable wrist and an adaptive grasping mechanism enabling it to pick up various object types. It is worth mentioning that this arm can be fitted for as low as 300USD which is ideal for amputees in low income countries like the ones in the African continent.

IV. CONCLUSION

The above projects provide a platform for future research to develop and test advanced prosthetic designs such as sophisticated EMG control algorithms, integrated pressure feedback and other advanced bio-mechatronic concepts and designs. With future growth of the 3D printing industry advanced printers and materials will allow anyone to develop more 'commercial-like' prosthetic devices – robust and durable systems that could benefit a wide range of peoples with a missing limb. Ongoing research improvements will hopefully lead to a system that is more durable and offers improved dexterity and control. Perhaps a future design will someday benefit amputees and improve the quality of people's lives.

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