DOI : https://doi.org/10.56452/7-796

ISSN: 0974-5823 Vol. 7 No. 01 January, 2022

International Journal of Mechanical Engineering

A Review On Development Of Assistive Upper Limbs For Amputations And Humanoids

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Abstract
Assistive devices are becoming prominent now a days for both human and humanoids. In case of human these assistive devices improvise the living conditions from either partial or full disabilities, on the other hand the humanoids use the same to sustain the functionalities similar to human beings. Of all these assistive devices artificial limbs are the mostly used ones and still there does not exist a sophisticated technology to use these artificial limbs to replace the functionalities that of natural limbs. This review focused on the parameters that play major role in the development of artificial upper limbs to perform the functionalities similar to the natural hands. The most important parameters that are considered for the development of these artificial hands in this review are like mechanism, degrees of freedom (DOF), control systems, and the materials and the technology used etc. The sophistications in functioning of the artificial hand increases with degrees of freedom but as the degrees of freedom increases the complexity in making the parts of the artificial upper limb increases for which technologies like additive manufacturing play's major role which cannot be done with traditional process. Still the limitations persist with this technology as well with the types of material used for 3D printing. Currently the materials used in 3D printing have certain drawbacks like absorbing energy in handling, where the material surface needed to be smoother and flexible to handle certain objects. So, focusing of the research for the possibility of employing better alternative materials like Auxetics and other smart materials for these artificial hands may be fruitful also have chances to optimize weight and space of wearable prosthetics.

Keywords: Assistive devices, artificial upper limbs, mechanism, DOF, Control Systems, 3D printing, Auxetics and other smart materials

Introduction
Bionic assistive devices are becoming most prominent in present living scenarios. These assistive devices that are being developed and available are for both partial and full disabilities, these are not only used in the case of amputations but also for modern humanoids that mimics human beings in assisting with self-intelligence. The history of these assistive devices is dated back to 18th century and is classified into three periods namely Foundation period before 1900, Establishment period from 1900 to 1972 and Empowerment period from 1973 to present. Prochazka et al in their work on assistive device for patents with C6 and C7quadriplegia designed an electronic glove which is fingerless that senses voluntary wrist movements electronically and provides Functional Electrical Simulation (FES) of muscles which controls the fingers to open the hand or to grasp a thing. The signals are sensed by the conductive surface which is in contact with electrodes assembled on selected muscles [1]. Similar work has been done by D Popovic et al but this is for C5 – C7 category spinal cord injury people in which they have improvised the power grasp and handling of bigger objects [2]. The assisting devices used in cases of amputees will be mostly for hands and legs. Even though huge amount of research work has been done in these cases but still there are gaps that are to be addressed. This article focuses bionic hands.

P. Antonescu et al in created a model with biomechanism for five fingered hand orientation and driving system. In this they have analysed the forces required for operating the fingers and mechanisms for functioning of the fingers based on the orientation of the fingers [3]. Paul H Chappel et al in their work on development of Southampton hand with 6 independent movements with an algorithm that selects manipulations and holdings automatically. This Southampton hand is equipped with different sensors like touch, slip, position and temperature sensors [4]. In another work by A. Kargov et al has designed and developed miniaturised hydraulic actuator for artificial hand. This actuator is designed in two ways one as standard and other as custom made and found that custom made actuator performed better than the standard actuator. The operating pressure of standard actuator is designed for 0-5 bar, direct acting with operating voltage of 5V and maximum flow rate of 274 ml/min. On the other hand, the custom-made actuator is designed for 0-6 bar operating pressure, direct acting with 6V operating voltage and maximum flow rate of 600 ml/min [5]. R. G. E. Clement et al in a review on bionic hands present technology and the future prospects found that the prosthetic hands are still inferior to that of the natural hands in many scenarios and as of the day the bionic hands are not fully replicating [6]. Xiancan Liu et al used graph theory for describing human hand grasp postures in order to define fingers movement as per the gripping requirement. In this method first hand tree is constructed based on the skeleton indexing, then the contact graph is designed based on the type of gripping posture required using basic cycle matrix. Six basic grasp postures are analysed based on contact graph based. This helps in virtual grasp description for bionic prosthetic hand [7]. Young June Shin et al designed high-performance prosthetic hand based on novel actuating principles. The appropriated muscles in fingers and fingertip powers are characterized by circulated incitation framework, double mode winding activation gives capacity to substantial impelling power and rapid movement and extra level of opportunity for the under activated automated hand is furnished with EM joint locking component. The appropriated muscles in fingers and fingertip powers are characterized by circulated incitation framework, double mode winding activation gives capacity to substantial impelling power and rapid movement and extra level of opportunity for the under activated automated hand is furnished with EM joint locking component. The specifications of the robotic hand designed in combination of these actuating systems are 10 DOFs, 5 fingers, 6 brushless motors and achievable grasp patters are power grasp, precision grasp & lateral grasp [8].

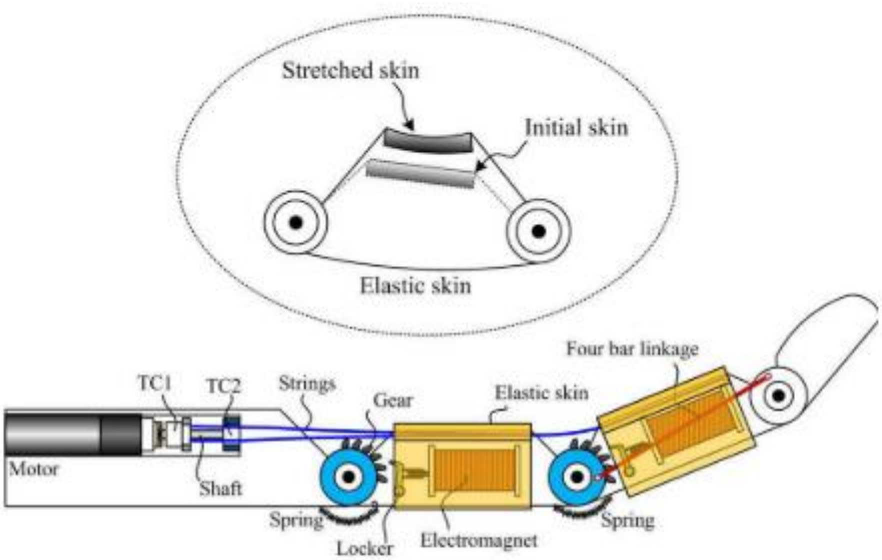

Figure 1. Conceptual Design Based on combined actuation principles [8]

D. Heaven in his article on restoring sense of touch through bionic hand analysed a subject for six weeks. Two tiny electrodes were implanted on upper arm of the subject one on ulnar, second on median nerve bundles where the purpose of these electrodes is to sense the electrical signals generated by the pressure pads on the tips of the finger and transmit the same through the nerves to the brain and the only drawback is that there is no way to know the quality of the signals but only thing is these senses can be felt [9]. Ebrahim Mattar conducted a survey on implementation of bio inspired robotic hand in which he detailed about biomimetic dexterous multi fingered robotic arm. This survey stated that there is a rich scope in kinematics, dynamics, modelling and controlling technologies in order to achieve more sophisticated biomimetic hands [10]. Kyung – Sun Lee et al in their review on ergonomic functioning of biomechanical hand focused on methodologies used to evaluate at stand point [11]. Diego Ferigo et al conducted a case study on bionic hand controlled by force myography. Naturally controlling robotic prosthesis by monitoring pressure or radial deformation of the limb for which force myography is an alternative. In this investigation both static and dynamic condition of forearm muscle contraction in shoulder and elbow are analysed by considering eleven different hand grips. It is found that there is 99% grip accuracy in static and 86% grip accuracy in dynamic condition with in trial analysis condition [12]. Wen – Tung Chang et al designed novel auxiliary creative mechanism for gripping of prosthetic hands. A systematic approach is used in modifying the existing devices with both topological structure and mechanisms. In this ATG 5F prosthetic hand is considered as appeared in figure 3. This prosthetic hand has planar six bar linkage with one DOF. The number of possible kinematic mechanisms is studied after which number synthesis algorithm is used to obtain possible number of linkages and joints. Based on the design constraints and requirements number of possible kinematic mechanisms are formed of which the best can be selected by replacing the existing one as described in figure 2 [13].

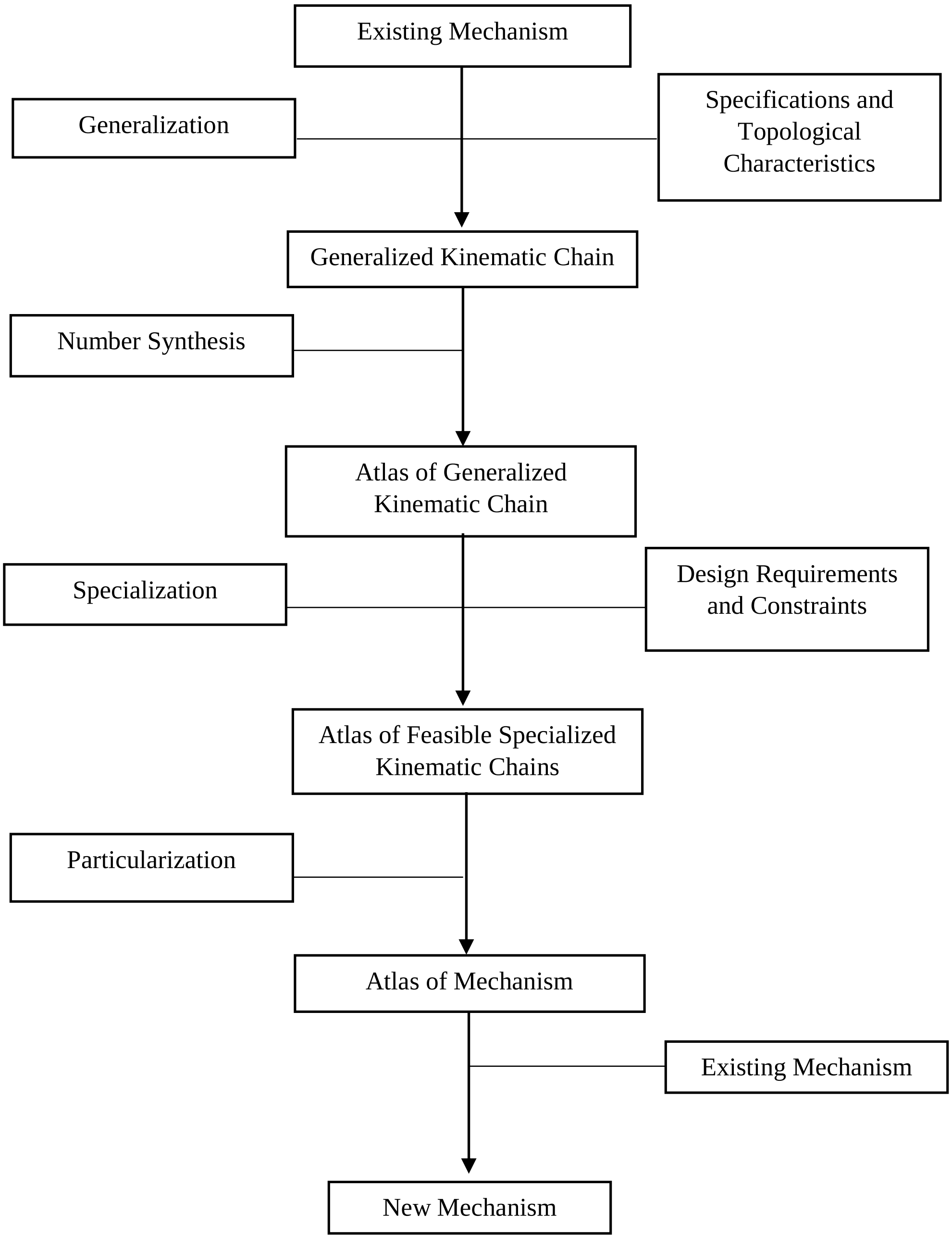

Figure 2. Creative Mechanism design for Prosthetic Hand [13]

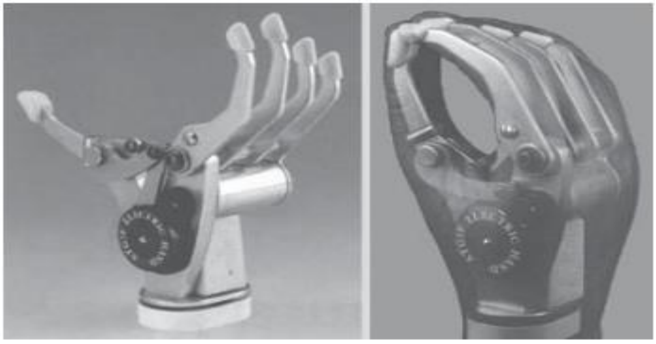

Figure 3. ATG 5F Prosthetic Hand [13]

M. Saiful Bahari et. al designed and developed Multifingered prosthetic hand with 14 degrees of freedom and is developed using rapid prototyping techniques. The finger joint movements in this prosthetic hand are achieved by pulley and belt mechanism driven by a servo motor which is located in palm. This prosthetic hand has an advantage of controlling using GUI, programming and manually [14].

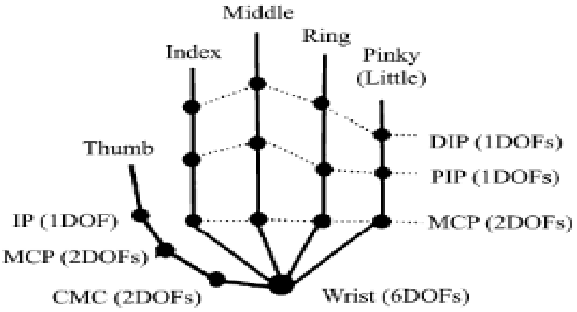

Figure 4. Representation of DOFs used in Prosthetic Bionic Hand [14]

K. Ayusawa et al in their work on human assistive devices, evaluated these devices by comparing with most advanced HRP-4 robot which have motion with high similarity to that of human being. This comparison is done in order to develop assistive devices for industrial standards for different applications. Two methodologies are utilized with the end goal to assess the assistive gadget (1) by estimating the joint torque of the robot with and without helping gadgets, at that point the thing that matters is assessed, (2) by utilizing inertial parameters of the robot without assistive gadget and assessing the joint torque for the equivalent with assistive gadget [15]. Alexandre Campeau – Lecours et al developed JACO assistive robotic device for people with disabilities which is empowered with innovative algorithms. This device is fixed to a wheel chair consists of an arm and gripper mounted to it and is commercially available. This is embedded with singularity and joint limit algorithm to have continues motion by avoiding the obstacles without stopping [16].

Figure 5. JACO Assistive Device Fixed to Wheel Chair of a Disabled Person [16]

GK Jones et al designed and developed a prosthetic hand by name Touch Hand II. This is a minimal effort prosthetic hand made by 3D printing innovation which is a distinct advantage substitution for existing financially accessible bionic hand and is intended for 14 DOFs. The fingers are actuated by six DC motors two for thumb and rest four for other fingers shown in figure 6, a microcontroller with feedback system is used with proportional integral controller to control torque and speed [17].

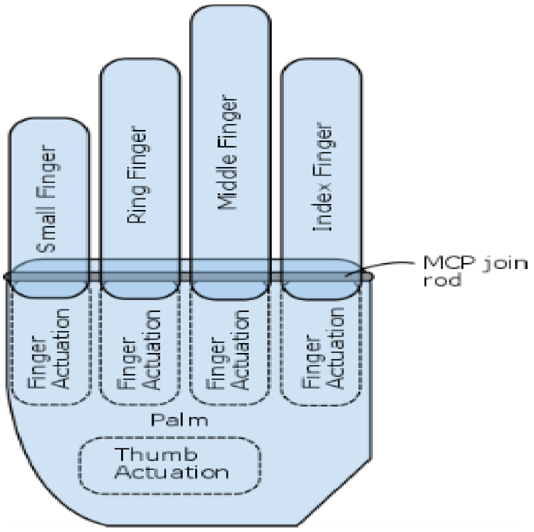

Figure 6. Actuation system for Touch Hand II [17]

Philipp Beckerle et al conducted a Delphi study to improvise mechatronics design of robotic hands especially sensory- motor skills. This Delphi study involves three rounds and the questioners where on kinematics of hand structure, kinematics its actuation & control and in the last round is on evaluation of round two and round three questioners for redefined design shown in figure 7 [18].

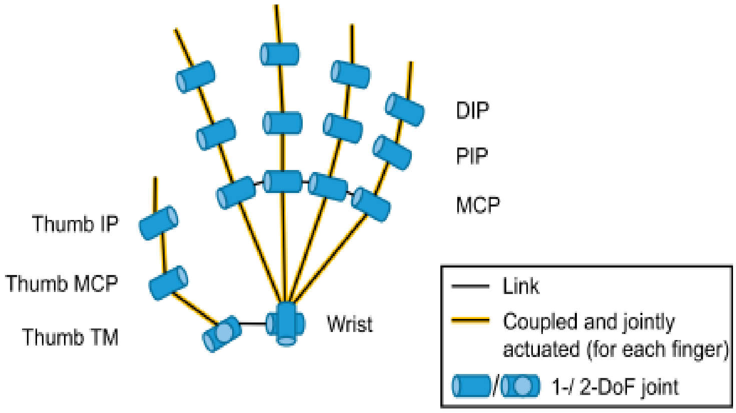

Figure 7. Modified Design Based on Delphi Study [18]

S. No.	Authors	Mechanism	Application
1	Huixu Dong et. al.	under-actuated tendon-driven	under-actuated tendon-driven robotic gripper with two 3-phalange fingers [19]
2	Mata Amritanandamayi Devi, Ganesha Udupa, Pramod Sreedharan	asymmetric bellow flexible pneumatic actuator (ABFPA)	Soft gripping application [20]
3	Kai Xu, Zenghui Liu, Bin Zhao, Huan Liu, Xiangyang Zhu	Composed continuum mechanism (CCM)	anthropomorphic hand design [21]
4	Shuangji Yao, Marco Ceccarelli, Giuseppe Carbone, Zhikui Dong	underactuated based on linkage and tendon mechanism with close-loop position and force feedback	grasping configuration of a three fingered robotic hand [22]
5	M. C. Carrozza, G. Cappiello, S. Micera, B. B. Edin, L. Beccai, C. Cipriani	sensorimotor mechanisms	cybernetic hand [23]
6	Clint Hansena, Florian Gosselin, Khalil Ben Mansour, Pierre Devos, Frederic Marin	kinematic chain of the exoskeleton	hand exoskeleton [24]

7	Seok Hwan Jeong, Ho Ju Lee, Kyung-Rok Kim, Kyung-Soo Kim	Twisted String Actuation (TSA)	Tendon-driven Robotic hand [25]
8	Paun ANTONESCU, Laurcntiu AI, VASILlU, Ovidiu ANTONESCU	Biomechanism (Tendon-driven)	Five Fingered Hand
9	M. Ceccarelli	Under Actuated Mechanism	Finger Mechanisms for Robotic Hands [26]
10	Wenrui Chen, Caihua Xiong	Tendon Pulley Under Actuated Linkage Mechanism	Anthropomorphic Hands [27]
11	Cl´ement Gosselin, Fr´ed´eric Pelletier and Thierry Lalibert´	Under Actuated Differential Mechanism	Anthropomorphic Underactuated Robotic Hand [28]
12	Gongliang Guo, William A. Gruver and Xikang Qian	Motor-Tendon Actuation	Robotic Hand with Rotating Finger Tip [29]
13	Yanjiang Huang, Xianmin Zhang, Jinying Zhang, Chihao Huang	Under Actuated Tendon Transmission Link Mechanism	Underactuated Robotic Hand [30]
14	Koichi Koganezawa, Nozomi Kunugi and Ryo Niikura	Under Actuated Mechanism with double planetary gear system	Artificial Finger [31]
15	Bart Peerdeman, Marcello Valori, Dannis Brouwer, Edsko Hekman, Sarthak Misra, Stefano Stramigioli	Tendon-pulley under actuation joint coupling and a series of joint locking mechanisms	UT hand I [32]
16	Young June Shin, Soohyun Kim, Kyung-Soo Kim	distributed actuation, dual-mode twisting actuation, and EM joint locking mechanism	Prosthetic Robot Hand with High Performances Based [33]

Table 1. Mechanisms Used in Different Bionic Hands and their Applications.

S. No.	**Authors**	**DOFs**	**Application**
1	Mata Amritanandamayi Devi, Ganesha Udupa, Pramod Sreedharan	25	Soft gripping application [20]
2	Kai Xu, Zenghui Liu, Bin Zhao, Huan Liu, Xiangyang Zhu	3 (2DOFs for Bending and 1DOF for Extension and Retraction)	anthropomorphic hand design [21]
3	Shuangji Yao, Marco Ceccarelli, Giuseppe Carbone, Zhikui Dong	8-12 depends on configuration of fingers	grasping configuration of a three fingered robotic hand [22]
4	M. C. Carrozza, G. Cappiello, S. Micera, B. B. Edin, L. Beccai, C. Cipriani	16	cybernetic hand [23]
5	Clint Hansena, Florian Gosselin, Khalil Ben Mansour, Pierre Devos, Frederic Marin	22	hand exoskeleton [24]
6	Paul H. Chappell, Andy Cranny, Darryl P.J. Cotton, Neil M. White, Steve P. Beeby	1	Myoelectric hands [4]
7	Cl´ement Gosselin, Fr´ed´eric Pelletier and Thierry Lalibert´	15	Anthropomorphic Underactuated Robotic Hand [28]
8	Gongliang Guo, William A. Gruver and Xikang Qian	9	Robotic Hand with Rotating Fingertip [29]
9	Yanjiang Huang, Xianmin Zhang, Jinying Zhang, Chihao Huang	15	Underactuated Robotic Hand [30]
10	Bart Peerdeman, Marcello Valori, Dannis Brouwer, Edsko Hekman, Sarthak Misra, Stefano Stramigioli	15	UT hand I [32]
11	Young June Shin, Soohyun Kim, Kyung-Soo Kim	10	Prosthetic Robot Hand with High Performances Based [33]
12	Tian Huang, Dong Zhao, Fuwen Yin, Wenjie Tian, Derek G. Chetwynd	6	hybrid polishing robot [34]

Table 2. Degrees of Freedom for different bionic hands

These things are one part of the bionic hands or the assisting devices, the other side of the coin is the technology used for developing these assisting devices. Now a days additive manufacturing or otherwise called 3D printing is widely used for developing prosthetics and most extensively in the assistive devices. The advantage of using these technologies is the development of the bionic hands with less weight, low cost and easy to manufacturing of the intricate shapes. Most of the

3D printing technology uses ABS, PLA, Polyamide, Polypropylene, titanium, aluminum, Michael King et al analyzed 3D printing and injection moulding technology to identify the better one which can be implemented with an optimized time and cost [35]. John Koprnicky et al have worked and evaluated different types of 3D printing technologies, materials used and the types of fasteners available at laboratory conditions, where they have concluded that the quality of the 3D printed prosthetic arms are closer to the commercially available and less cost [36]. Marcelo H. Stoppa et al developed 16 DOF bionic hand by 3D printing technology where PLA (Polylactic Acid) material used. The advantage of this PLA is that the material is biodegradable with considerable mechanical resistance [37]. Farah Alkatib et al conducted benchmarking analysis for low cost 3Dprinted material on two different materials under different loading conditions for evaluation of grasping force [38]. L Ali et al have done micromechanical modelling of 3D printable interpenetrating phase composite and found that by using complaint matrix material and large re-entrant angles negative Poisson’s ratio can be developed [39]. Da Chen et al in their technical article on additive manufacturing of metamaterials with negative Poisson’s ratio discussed about difficulties involved in developing Multi-material with negative Poisson’s ratio in compared with the natural structures that have the similar properties. Also stated that even though this have profound applications, the usage of distributed modulus can be configured for guided cell growth in biological applications [40]. Huachen Cui et al fabricated 3D micro architected silicon based metamaterials for high temperature applications using additive manufacturing technology [41].

Conclusion

The development of technology is driving the improvements in the development of prosthetics. As the modern-day prosthetics are coming with many advancements in features as well as resembling more natural to the existing one, not only this but also these bionic assistive devices are becoming more easier to wear by the amputees. This paper focus on the review of the technological advancements in prosthetics especially on bionic hands. Even though there are different mechanisms available for driving these bionic hands, the most commonly used is tendon driven mechanism because of simplicity in arrangement compactness and actuates smoothly comparative to other mechanisms. On the other side, with technological updates researchers are working to increase the degrees of freedom for this prosthetic hand to use it more sophisticatedly. With the increase in number of degrees of freedom the complexities in making the parts of the bionic hand also increases. In this scenario 3D printing play major role in developing these complex parts and most of the bionic hand models developed by the researchers are using this 3D printing technology with commonly used materials like ABS, PLA, Polypropylene etc… are used.

Even though these materials are most commonly used for developing bionics based on certain advantages, in practical there are certain limitations where the materials need to absorb energies in handling, the surface needed to be smoother and flexible to handle certain objects and the research can be further focused on employing Auxetics for bionic hands and micro-mechanisms which can still optimise weight and space of the wearable prosthetics.

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