Overview: Mechanism and Control of a Prosthetic Arm

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Overview: Mechanism and Control of a Prosthetic Arm

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Abstract: Continuous growth in industrialization and lack of awareness in safety parameters the cases of amputations are growing. The search of safer, simpler and automated prosthetic arms for managing upper limbs is expected. Continuous efforts have been made to design and develop prosthetic arms ranging from simple harness actuated to automated mechanisms with various control options. However due the cost constraints, the automated prosthetic arms are still out of the reach of needy people. Recent data have shown that there is a wide scope to develop a low cost and light weight upper limb prosthesis. This review summarizes the various designs methodologies, mechanisms and control system developed by the researchers and the advances therein.

Educating the patient to develop acceptability to prosthesis and using the same for the most basic desired functions of human hand, post amputation care and to improve patient's independent life is equally important. In conclusion it can be interpreted that there is a wide scope in design in an adaptive mechanism for opening and closing of the fingers using other methods of path and position synthesis. Simple mechanisms and less parts may optimize the cost factor. Reduction in the weight of the prosthesis may be achieved using polymers used for engineering applications. Control system will remain never ending challenge for the researchers, but it is essential to maintain the simplicity from the patients perspective.

Keywords: Amputation, Prosthetic arm, automated prosthesis, bionic arm, multi fingered robotic hand.

1 Introduction

Amputation is taken from the Latin term "amputare" meaning "to cut out" is the removal of a limb by trauma, medical illness, or surgery, as a surgical measure used to control pain or a disease process in the affected limb, such as malignancy

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or gangrene. (on line medical dictionary). Generally amputation in the upper limbs are seen in situations like congenital limb deficiency, rail, road accidents, fire or electric shocks, loss of arm in agriculture equipment, amputation due to disease cancer, diabetics or trauma, animal or reptile bite, accidents at construction and war related injuries land mines, frost bites etc. In the literature the categories are also differentiated as amputations in civilian and military personals.

Due to continuous growth in industrialization and lack of awareness in safety parameters the cases of amputations are growing. The effect of limb amputations results in mental trauma of missing of natural body part loss of activities performed by hand, loosing employment opportunities, physical dependability on other members of the family, fear of social disconnection, medical problems due to amputation. Prosthesis is an artificial body part to regain the functional ability to perform basic movements without the help of manual support. Prosthetic arms are required for those who suffer either loss of upper extremity limb due to accidents or are born with a physical disability (medical dictionary).

The importance of the form in prosthetics cannot be ignored. To increase the prehensile capabilities design team often sacrifices the cosmetic appeal. It depends upon the user, some may be concerned about functional capabilities of the device, others may be more interested in the realistic human like look of the prosthesis. The cosmetic appearance as aesthetically pleasing and looks like limb it is supposed to substitute. So a device may be statically correct but look wrong if it is lifeless when talking about to be in motion. People see what they expect to see, if the wearer of the prosthesis moves the artificial limb in natural way, a casual observer may not notice it. Limb replacement should be anthromorphic in shape, size and outline. This never indicates that an artificial hand is required to appear like real human hand. Weir and Sensinger (2003) in his article discussed about anatomical design considerations, multifunction mechanisms, controls, safety features required for the development of upper extremity prosthesis. He considered a prosthetic arm more tool rather than a limb replacement. The design team needs an understanding of the mechanics of mechanisms, such as gears, levers, and points of mechanical advantage and electromechanical design, such as switches, dc motors, and electronics. In addition to mechatronics the prosthetics designer must also have knowledge of muscloskeletal anatomy and muscular- as well as neurophysiology.

The importance of the prosthesis is well presented by McGimpsey and Bradford (2014) on the Market analysis of limb prosthetics services and devices. There are numerous designs developed by the researchers and product designers to make a mechanism which can perform like a real human hand. O'Keeffe (2011) of Ottobock reviewed the scope of the upper limb prosthesis, the issues related to cost, cosmetic & functional restoration functional devices, control system and its limitations.

Belter and Dollar (2011) reviewed performance characteristics of commonly used prosthesis and anthropomorphic devices. The initial research was limited to a few specific motions like two finger gripping. The links were actuated by set of harness which controlled the opening and closing functions of links (fingers). These prostheses were named as harness controlled non automated devices. Further development resulted controls of the mechanisms using electric motors and actuators categorized as automated prosthetic hands.

Jefferies (2015) in his Doctoral research *'Just Normal: A Grounded Theory of Prosthesis use',* The aim study was to explore a core concern of prosthesis users and to develop a theory of how this concern is managed. By employing classical Grounded Theory methodology, data from 24 participants that used upper- and/or lower-limb prostheses were collected and analyzed.

Mariappan, Jan and Iftikhar (2011) introduced concept named as "Coefficient of UAM" which is the ratio between numbers of motors to the number of DOFs". In under actuated hand prostheses, depending upon control strategy used one can get more and more degree of freedoms to make its prosthetic device more versatile and easy to control. By reviewing various known studies, CoUAM of randomly selected prosthetic hands is calculated separately and analyzed merits/demerits, cost, weight, appearance, ease of controllability and their functionality to make this approach more objective and useful for the future researchers.

An individual's response to the artificial limbs may be attributed to several factors including external and physiological environment, overall health profile, individual needs, economic condition of the patient and the severity of amputation and most importantly type of the prosthesis used by the patient. Apart from functional aspects the cosmetics i.e appearance as natural one also has major role in selection of prosthetics.

This literature review explains about the various design and development methodologies followed for the development of the prosthetic hand. The paper is divided in three parts - Classification, Mechanism and controlling a prosthetic hand.

2 Classification of Prosthetic hand/arm

Similar to the other consumer products the prosthesis has followed the stages of evolution, development and innovation. Replicating any human part is not an easy task. Researchers have to repeatedly reanalyze the need of the prosthesis on the basis of the expectations of the patient keeping in mind age, sex and the profession. This literature survey revealed many researchers in race to design most efficient and perfect 'machine' which exactly looks like a real hand and works like a real

Table 1: Presents Classification of Prosthetic as per amputation

SN	Type of amputation	Type of Prostheses
1	Shoulder disarticulation.	From Shoulder
2	Elbow disarticulation.	Below Elbow. Above Elbow.
3	Wrist disarticulation.	Below Elbow.
4	Trans carpal disarticulation	Below Elbow.
5	Finger amputations	Below Elbow.

hand.

Automated Prosthetic arms are considered as biomedical devices and developing the same is interdisciplinary activity i.e combination of mechanisms and electronics. The selection of prosthetic arm depends upon type of the disarticulation the patient has undergone and the patients need. Please refer figure 1.

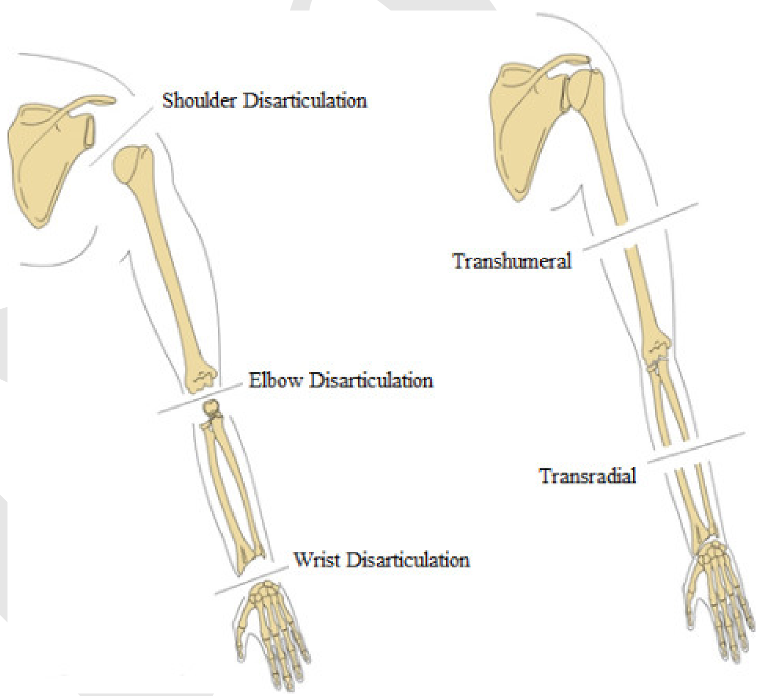

Figure 1: Amputation level
(Image curtsey www.wheelessonline.com)

2.1 Amputation above elbow (AE) or Transhumeral Prosthesis

It is an artificial limb which replaces an arm missing above the elbow. It has complexities related to movements to the fingers, wrist and elbow. Refer figure 2.

Figure 2: Transhumeral Prosthesis
(Image curtsey Ottobock)

2.2 Amputation Below elbow (BE) or Transradial Prosthesis

It is an artificial limb which replaces missing arm below the elbow.

Figure 3: Transradial prosthesis
(Image curtsey Center for Prosthetics Orthotics, Inc)

Prosthesis are available for patients under this category, may be further classified as:

2.2.1 Cosmetic Prosthesis

It restores limited functional aspects of the portion of missing body part. It may be designed to passively grip or hold any object. Used for missing finger or entire arm from the shoulder. The cosmetic appearance of the artificial body part is emphasized more than functional aspect.

Figure 4: Cosmetic Prosthetic Arm (Image curtsey Ottobock).

2.2.2 Body Powered Prosthesis

A Prosthesis which is actuated using cable attached to a harness which secures prosthesis on the patient's body. The selection of the prosthesis depends upon the level of the amputation the patient has undergone and the availability of the residual limb relative to the patient's body part to control and power the function refer figure 5.

Figure 5: Body Powered Prosthetic arm (Image curtsey onesmileonearm.wordpress.com)

2.2.3 Myo Electric Prosthesis

It uses electrical action potential of the residual limb's muscles that are emitted during the contraction of the muscles. These emissions are measurable on the skin surface at a microvolt level. The Myo electric signal also called as motor action potential is an electrical impulse that produces contraction of muscle fibers in the body. It has frequencies ranging from few Hertz to about 300 Hertz and voltages from 10 microvolt to 1 milli volts. Myoelectric signals are detected by placing three electrodes on the skin. Two electrodes are placed to develop voltage difference when there is contraction in muscle and the third one in the neutral area, its output is used to cancel the noise produced by other two electrodes. This voltage is amplified which produces significant current to control the electromechanical and electronic devices. This is now used in commercially available existing automated prosthetic arms.

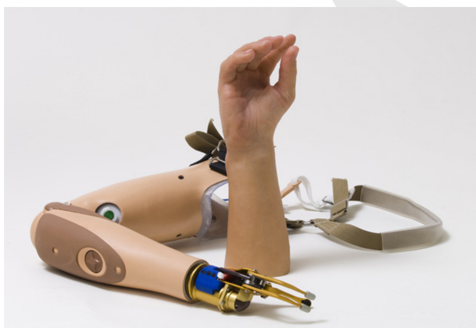

Figure 6: Myo electric Prosthetic arm
(Image curtsey West Coast web & Limb)

3 Commercially available Smart Automated Prosthetic hands

RSL Steeper, Ottobock and Touch Bionics are globally renowned companies producing range of smart automated prosthetic hands. EXIII a Japanese company is emerging out with it range of latest state of art prosthetic hands.

3.0.1 Dynamic Arm above elbow Prosthetic arm, Ottobock

As claimed it can open and close almost three times faster than other hands 300 mm a second and it has auto grasp feature with sensor technology which can tell when an object holding begins to slip. The motor makes the Dynamic Arm (Figure) elbow twice as fast as other electric elbows 0.5 seconds from extension to full flexion. The elbow is proportional in speed and can actively lift up to five kilogram and static holding capacity of twenty kilogram. Smooth flexing and extending due to vario drive clutch. The elbow's automatic forearm balance takes advantage of the energy that is stored when the arm is extended and reuses it for flexion.

Figure 7: Dynamic Hand (Image curtsey Ottobock)

3.0.2 be-Bionic, RSL Steeper

bebionic hand is a RSL Steeper smart hand with unique ergonomic features which has given the hand unrivalled, versatility, functionality and performance. Each finger is powered by individual motor for natural coordinated grip and hand movement, controlled by powerful microprocessors which monitors the position of each finger, giving precise, reliable control over hand movements.

The motors are positioned to optimize weight distribution making the hand feel lighter and more comfortable. It has fourteen selectable grip patterns and hand positions resulting wide everyday activities. It has auto grip function to avoid slipping of gripped item, foldaway fingers for natural looking movement. The hand costs between $25,000 and $35,000. Refer Figure 8.

3.0.3 I-Limb hand from Touch Bionics

I-limb has instant access to 36 grip options and gestures. It has automatically individually motorized digits and precision rotating thumb. Its capable of mimicking natural grasp patterns of the hand due to programmable grip patterns and gestures. Unique wristband design allows user to maintain wrist range-of-motion while open forearm reduces heat & sweating. It has control options as EMG muscle signals and mobile App. Refer Figure 9.

Figure 8: Bebionic Hand (Image curtsey RSL Steeper).

Figure 9: I - Limb hand (Image curtsey Touch bionics)

3.0.4 Michelangelo Hand, Ottobock Inc.

The new Michelangelo Hand from Otto Bock features a thumb that electronically moves into position, enabling it to function more like a human hand. The Michelangelo Hand has multiple grip functions that allow users to master everyday tasks like opening a tube of toothpaste, gripping a key, holding a credit card, and using a clothes iron. The thumb can also open up to create a natural palm shape for holding a plate or bowl, and the flexible-positional wrist joint offers a more natural shape and movement. Advanced software and EMG signal processing increases the responsiveness and predictability of the Michelangelo Hand. Refer Figure 10.

3.1 Handiii, from exiii Inc. Japan

A Japanese Company established by Genta Kondo Using smartphone to process muscle signals. Wirelessly collects signals from skin surface. Detects the hand motion intended by the user. Reduction in motors; One motor per 3DOF fingers, Mechanism adaptive to various sizes and shapes.3D printer production for Reduce production cost & Easy to repair and customized design. (Refer Figure. 11)

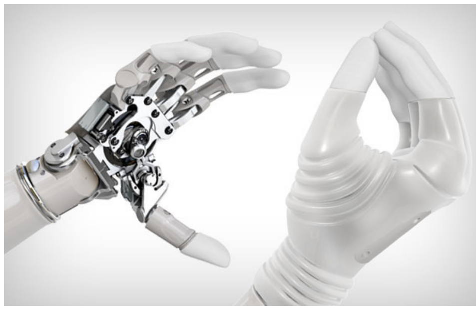

Figure 10: Michelangelo Hand from OttoBock

Figure 11: Handiii from exiii

4 Popular Research Projects for the development of Prosthetic hand

4.1 APL Smart hand (JHUAPL & DARPA)

James Burck et al. at John Hopkins University Applied Physics Laboratory (APL) and Defense Advanced Research Projects Agency DARPA have worked to develop a smartest arm driven by neural inputs and sensory feedback technologies to enable the perception of physical inputs such as pressure, force and temperature in addition to adaptive gripping. Figure 12 depicts APL Smart hand.

The Modular Prosthetic Limb features:

- Anthropomorphic (lifelike) form factor and appearance
- Human-like strength and dexterity
- High-resolution tactile and position sensing
- Neural interface for intuitive and natural closed-loop control

The two prototype limbs developed for the DARPA program use Targeted Muscle Reinnervation, a technique pioneered by Dr. Todd Kuiken of the Rehabilitation

Institute of Chicago. This technique involves the transfer of residual nerves from an amputated limb to unused muscle regions near the injury. In a clinical evaluation, the first prototype enabled a patient to complete a variety of functional tasks, including pulling a credit card from a pocket.

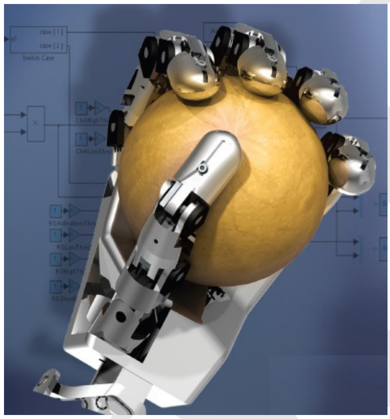

Figure 12: APL Smart hand (Image curtsey APL & DARPA)

4.2 DEKA ARM, DEKA Research and Development Corporation

Dean Kamen, the founder DEKA Research & Development Corporation to develop internally generated inventions as well as to provide research and development for major corporate clients. The robotic arm is a DARPA funded project intended to restore functionality for individuals with upper extremity amputations. Refer figure 13.

Figure 13: Deka Arm (Image curtsey DEKA Research Project)

4.3 NAIST ARM, Nara Institute of Science and Technology

The ‘NAIST Hand Project’ was started at Nara Institute of Science and Technology in 2002. They proposed a vision-based slip margin estimation and grip force control by its direct feed back using tactile sensation and manipulation. The hand has four fingers and each finger has three degree of freedom. Its specially designed gear mechanism has relaxed the restriction on the space for actuators, and all actuators are embedded in the palm. Refer Figure 14.

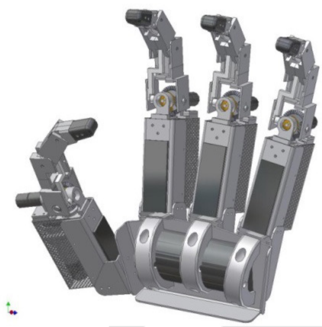

Figure 14: Naist Arm (Image curtsey NAIST, Japan)

4.4 Project Cyber Hand

The cyber hand project was funded by the Future and Emerging Technologies (FET) arm of the IST Program, it aimed at exploring theories and solutions in the fields of neuroscience and robotics, in order to develop a cybernetic prosthetic hand, paper presented by Roccella, Carrozza, Cappiello, Cabibihan, Laschi, Dario, Takanobu, Matsumoto, Miwa, Itoh et al. (2007).

Six partners from four countries Scuola Superiore Sant’Anna University Pisa Italy, INAIL Prosthetic Centre Pontedera Italy, Institute of Microelectronics of Barcelona IMB-CNM Barcelona Spain, Fraunhofer Institute for Biomedical Engineering St. Ingbert Germany, Universidad Autonoma de Barcelona, Spain and Center for Sensory-Motor Interaction, Aalborg University, Denmark. Collaborated on this project. The objective project was focused on the development of a new kind of hand able to re-create the natural link which exists between the hand and the Central Nervous System Theproject was targeted towards developing a bionic hand close to natural one.

The Cyber hand is controlled by an amputee in a very natural way, by processing the efferent neural signals coming from the CNS. The prosthesis will be felt by the amputee as the lost natural limb since a natural sensory feedback will be delivered to him/her by means of the stimulation of some specific afferent nerves). The project resulted RTR1, RTR2, Spring and Cyber hand.

4.4.1 RTR1 Hand

The RTR1 hand is composed of a palm with three fingers, two equal fingers having three phalanxes, and the third finger as thumb with two phalanges. The RTR1 hand weighed 250 grams. This model of mechatronic hand has six independent degrees of freedom and two passive DOF. The sensory system is composed of six position sensors for detecting the angular displacement of the active joints and three force sensor on the fingertips. Refer Figure 15.

Figure 15: RTR1 Hand (Image Curtsey Future and Emerging Technologies)

4.4.2 RTR2 Hand

In the RTR2 hand, the actuation system is based on the concept of under actuation. In other words the fingers can self-adapt to the object shape with a simple movement of a slider linked to the finger through a steel wire. The hand is powered by two DC actuators integrated in the palm for the actuation of fingers. First one used only for the thumb positioning and the second one moves the slider and pulls the wires, in such a way that all the three fingers close together towards the object. The RTR2 hand weighed 350 grams. The control system is embedded in the palm and its sensory system is composed of proprioceptive and exteroceptive sensors. (refer Figure)

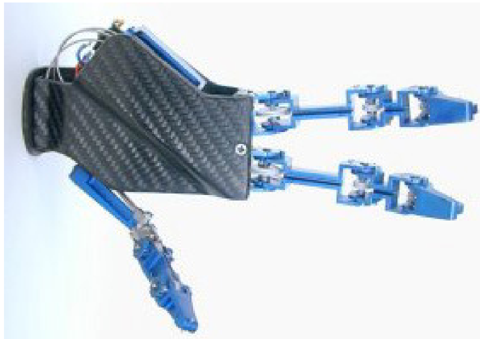

Figure 16: RTR2 Hand (Image Curtsey Future and Emerging Technologies)

4.4.3 Spring Hand

In the spring hand, the actuation system is based on the concept of under actuation. One DC actuator integrated in the palm, actuates the hand. The movement of the slider, bringing the wires in tension, causes the flexion of all the fingers. The SPRING hand weighed 400 grams. Its sensory system composed of a tension sensor fixed to the slider in order to continuously monitor the cable tension applied by the motors.

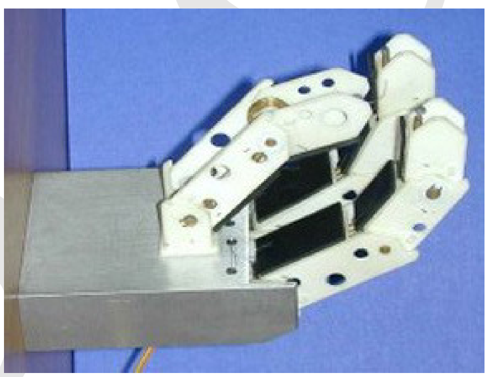

Figure 17: Spring hand (Image curtsey Future and Emerging Technologies)

4.4.4 Cyber Hand

The three fingered RTR2 hand was redesigned to improve the hand grasp functionality and its anthropomorphism, all the phalanges have a cylindrical shape without sharp edges. Their dimensions are much closer to the anthropomorphous ones and the proximal phalanges have a diameter of only 16 mm. Each finger is under actuated and the mechanism is the same of the RTR2. Six number of DoFs, six number of DC motors, tendons as type of transmission, Trapezo-metacarpal thumb joint abduction/adduction range, finger joints flexion range from 0-90, 40 N maximum grasping force during cylindrical grasp, 15 N maximum tip to tip force. It is designed for cylindrical, spherical, lateral, tridigital, bidigital grasping capabilities. Having 450 grams weight of the hand structure. The Electronical characteristics as twenty one position sensors, eight force sensors, fifteen touch sensors one for each phalanx. Position, velocity and force controlled grasping. Refer figure

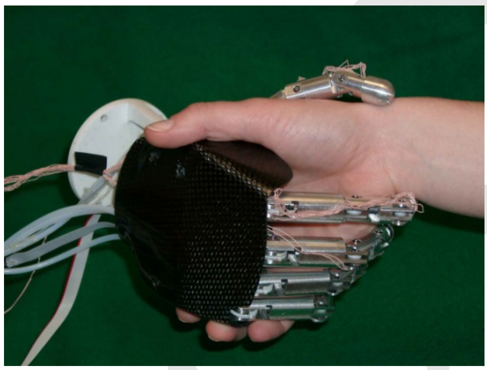

Figure 18: Cyber Hand (Figure Curtsey Future and Emerging Technologies)

4.5 SARAH Hand (under actuated robotic hand for the Canadarm) Highly Underactuated 10-DOF Robotic Hand (for the Canadarm)

The new hand, SARAH (*Self Adaptive Robotic Auxilary Hand*) designed with 12-DOF. The earlier robotic hands developed in the laboratory had an under-actuation only in the fingers. Each finger was actuated by its own motor. In 1998 the company MDA Space Missions contacted the laboratory in order to request the development of a hand for the well-known Canadarm. One of the specifications requested for this new hand was that it should be actuated by only two motors. This led to the principle of a hand featuring under actuation among the fingers the opening and closing of the fingers is controlled by only one motor. The study shows only one motor is sufficient as it is not necessary for all three fingers to close independently, because all fingers will close to grasp an object as firmly as possible. If one finger is firmly wrapped around an object, the other fingers will continue to close until all fingers are firmly closed. The under actuation among the fingers is achieved through an innovative gear differential mechanism. A second motor allows the orientation of the fingers to be changed to achieve cylindrical, spherical and planar grasps.

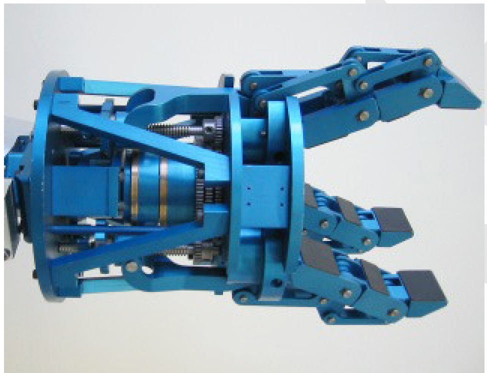

Figure 19: Sarah Hand (Image Curtsey Sarah Nasser et al.)

4.6 *Partial hand prosthesis, an applied case at Universidad Nacional de Colombia*

Engineers from Universidad Nacional de Colombia designed a partial hand prosthesis with mechanical functions. This prosthesis is targeted people under low income fabricated in stainless steel.

Figure 20: Partial hand (Image Curtsey Universidad Nacional de Colombia)

4.6.1 *Toronto Bloor view Macmillan (TBM) Hand Multi-Fingered, Adaptive Grasp Prosthetic Hand*

Dechev, Cleghorn and Naumann (1999, 2001) developed TBM hand which constituted design a multi-fingered, adaptable grasp prosthesis for children in the 7-11 age group. Six links in each finger, four links in the thumb with combined weight of fingers, thumb & pins 45 grams. With Single I DOF of actuation for four fingers and one for thumb. Refer figure 20.

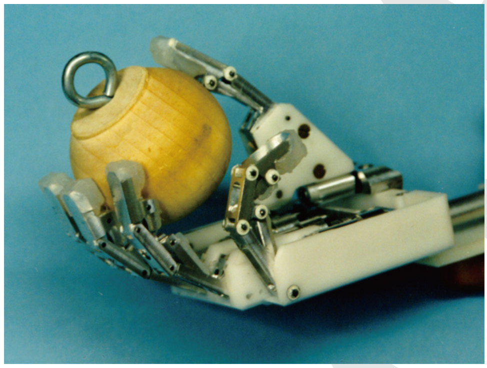

Figure 21: TBM Hand (Image Curtsey Toronto Bloor view Macmillan Hand)

4.7 *Victoria Hand*

The Victoria Hand is a complete body-powered prosthesis consisting of a hand, a wrist, a limb- socket, and a harness. It has high functionality, natural-appearance, and is custom-made to fit each amputee. The hand is capable of adaptive grasp, which allows the fingers and thumb to conform around the shape of various objects, creating a secure grip. As well, the fingers and thumb are rubber-tipped to help grasp smaller objects. The prosthesis has an adjustable ball-and-socket wrist, to orient the hand to various postures. The wrist is easy and intuitive to use and gives the amputee ability to perform many different tasks. Refer Figure 21.

Figure 22: Victoria Hand (Figure Curtsey Victoria hand Project)

4.8 Southampton hand

The Southampton Artificial Hand gave foundation for the research in prosthesis the mechanics of the Southampton hand has evolved with new designs, it is the main control hypothesis that forms the foundation of the Southampton Hand. In order to grip an object with a natural hand, the brain utilizes information from sites all over the hand and fingertips, to provide muscular reflexes for conformed gripping. The Southampton philosophy concentrated on devolving the responsibility of grip adjustment from the user to the hand itself. The 'intelligent' hand used sensors, electronics and microprocessor technology to allow this adaptive device to maintain optimum grip. Please refer Figure no 22.

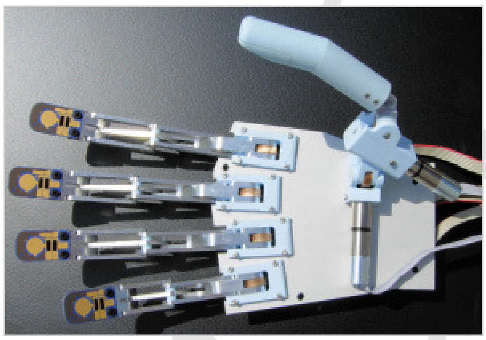

Figure 23: Southampton Hand (Figure Curtsey ECS, University of Southampton)

5 Prosthetic arm and mechanism

A prosthetic arm is a combination of various links, levers with appropriate joints in an open or closed mechanism. These links or bodies as assembled in such a way that the motion of one causes constrained and predictable motions to others. So it forms a machine which is combinations of various mechanisms which imparts motions to the links, transmits and modifies the mechanical energy into desired work. There are numerous designs developed by the researchers and product designers to make a mechanism which can perform like a real human hand. The initial research was limited to a few particular motions like two finger gripping or three fingers gripping. The links were actuated by set of cable and harness which controlled the opening and closing functions of links (fingers). These prosthetic hands were named as harness controlled non automated arms. Further development leads towards the controls of the mechanisms using electric motors and actuators making them automated prostheses. Various requirements of automated prostheses were identified as smooth gripping of the object, orientation of the arm if designed from the shoulder, a friendly compatible control system, light weight, aesthetic looks to appear real and a reliable power input to make it working with better durations. A prosthetic limb consists of three basic components the socket, which is the interface between the limb and the mechanical support system, the extension (or pylon) which replaces the length of the lost limb, elbow joint if the amputation is above the Strait (2006).

The traditional body controlled prosthetic arm comprises of following parts:

- Socket or interface.
- Suspension system.
- Harness
- Control cable.
- Wrist unit.
- Terminal device (hook or hand)
- Three or two finger caliper type gripper.
- Single Digit design without adaptive gripping.
- Other accessories tricep cuff, hinges, elbow, shoulder depending upon the disarticulation.

Figure 24: Terminal Device (Image curtsey Ottobock)

Body powered terminal devices include hooks or mechanical hands. These are actuated in two options:

a. Voluntary opening to remain closed until pull on the cable opens them. Relaxing closes the TD around an object with a grip force determined by a pre-set resistance.

b. Voluntary closing to remain open until pulling on the cable closes it with a grip force proportional to the amount of force the person puts on the cable.

Hooks come in various shapes and sizes. They can be made of aluminum, steel, or titanium and can be rubber lined for better gripping. The amount of force a voluntary opening hook can hold with (called grip force) is determined by the number of rubber bands holding the hook closed. Terminal devices may also be hands. They are more cosmetic, but they are also more bulky and grip force tends to be less. Wrist units connect the TD to the prosthesis and restore some of the function of the anatomical wrist. These are classified as:

1. Friction Wrists: Its allows passive rotation and positioning by the other hand.

2. Locking Wrists: It can be locked in a different positions to prevent rotation when grasping or lifting.

3. Quick Disconnect: It allows swapping of TDs. Some models lock in various positions.

4. Flexion units: It provides wrist flexion or bending, usually requires pressing a button to allow bending and to release it from a locked/bent position.

The major parts of an automated prosthetic arm are as follows:

- Socket or Interface (foundation of prosthesis)
- Suspension system.
- Electric motors to transmit the motion.
- Power supplied by low voltage rechargeable battery.
- Controlling the motors using myo electric signals.

Commercially available prosthetic arms are either harness controlled or myo-graphically controlled. The harness controlled prosthetic arms are low cost but have limited functions, more weight and inferior cosmetics causing unpopularity amongst the user.

Table 2: Depicts comparison between body powered and myo electric powered prosthetic arm.

SN	Features	Body Powered	Myo electric powered
1.	Functions	Limited	Limited
2.	Control System	Cable & Harness	Myo Electric
3.	Electrical Power	Not required	Battery
4.	Sensors	Not applicable	External EMG sensors
5.	Wearing	Takes time	Quick and easy
6.	Mechanism	Three finger caliper type	Three finger caliper type
7.	Wrist yawing motion	Not available	Not available **
8.	Cosmetic looks	Inferior	Better with real looks.
9.	Gripping force	No control	Can be controlled
10.	Adaptive Gripping	Not available	In Higher models.

6 Kinematic Modeling and Designing

Kinematics is a study of body under motion without regard to forces. A mechanism consists of a kinematic chain in which at least one link is grounded or attached to reference frames. A kinematic chain or a linkage is an assemblage of links and joints interconnected in such a way to provide a controlled output motion in response to a supplied input motion. Combination of mechanism or a mechanism forms a machine. Kinematic modeling is a mathematical and scientific method to compute dimensions, position, velocities and acceleration of a member or a part which forms a machine. It is the first step to define and decide the constrained motion of the members of the parts in a machine using graphical or analytical methods. The mechanism is derived from synthesis which is determination of effective working dimensions of the links in a kinematic chain for required positions of the members or parts. An artificial hand is a mechanical machine which is required to mimic the working of a real human hand. To design a mechanism for a hand it is essential to "synthesize" the moving parts in artificial hand or prosthetic hand most importantly designing a finger which finally holds the object. Defining the motion of a finger providing under actuated gripping to the object to be held.

The links of a mechanism used in a upper limb prosthesis are analogous to biological bones of hand. It is very difficult to mimic exact motion of a natural hand, but at a greater extent can be made closer to the same. The reaching movement of a prosthetic arm is important task required for daily activities. Synthesis of finger mechanism is thus first step to design a gripper for a prosthetic arm. This section of paper explains various kinematic models formulated by scientists and researchers in the direction to achieve a mechanism to work as real human hand.

We have attempted to refer most cited technical papers to make effective research review in this section. Almost all the papers referred have primary objective to design an under actuated mechanism for a digit (finger).

Pons, Rocon, Ceres, Reynaerts, Saro, Levin and Van Moorleghem (2004) presented the mechanical design and manipulation aspect of multifunctional project upper limb prosthesis developed under MANUS – Hand project. They designed for four under actuated, multi fingered dexterous hand with grasping modes cylindrical, precision, hook and lateral using two actuators. In their design, they used crossed tendon mechanism instead of four bar mechanism. The thumb movement was coupled by means of a Geneva wheel based mechanism which made it possible to use one actuator for the thumb movement in two planes. Ultrasonic motors were used to drive the wrist pronation and supination. It comprised of ten joints out of which three were independently driven and individual mechanism for finger, thumb and wrist. The MANUS Hand concept proposed fingers with three coupling joints, the coupling of joints a relationship was imposed between the angles of phalanges to obtain required flexion pattern. In order to evaluate the quality of the actuation type they eleven properties relative to prosthetics were considered. No detailed information on the synthesis of the mechanism is reveled.

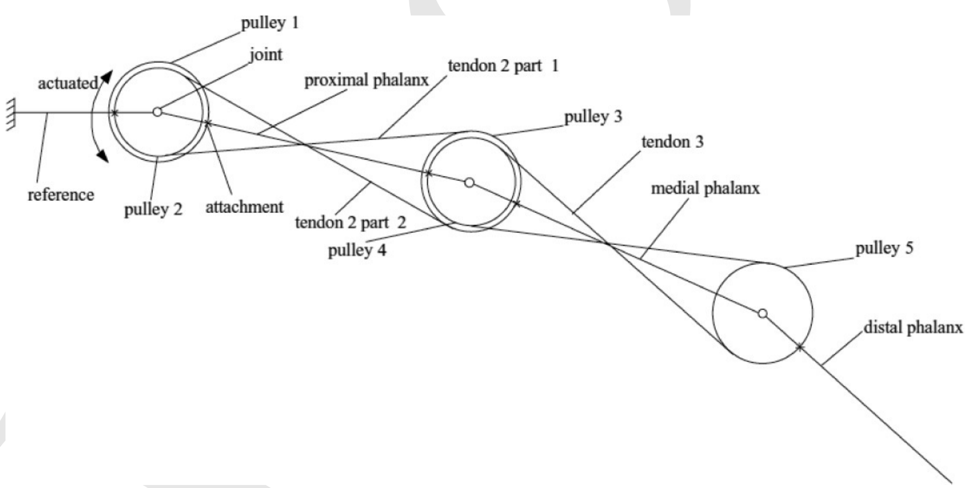

Figure 25: Joint coupling through crossed tendon mechanism J. L Pons et al.

Carbone, Rossi and Savino (2015) This paper describes two robotic hands that have been developed at University Federico II of Naples and at the University of Cassino. Federica hand and LARM hand are described in terms of design and operational features. Federica hand uses tendons and pulleys to drive phalanxes, while LARM Hand uses cross four-bar linkages.

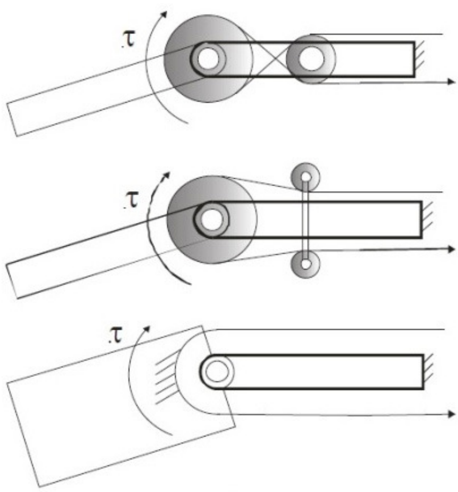

Figure 26: Pulley driven mechanism Carbon et al.

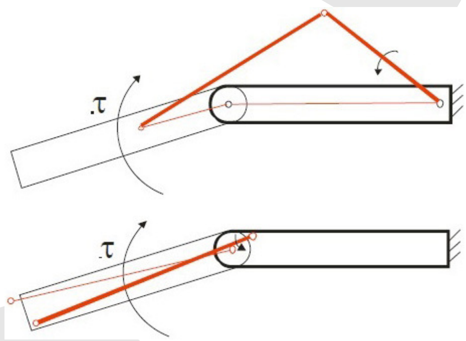

Figure 27: Linkage driven mechanism Carbon et al.

Federica hand is composed of five fingers each made of three phalanxes with revolute joints. Each finger has antagonistic tendons rigidly connected with distal phalanx. Tendons are actuated in traction only. The finger regains its rest configuration by elastic spring element. It requires only one actuator for controlling five fingers.

The Displacement of the pulley is established by equations;

$X_1 = X_A + \boldsymbol{\theta}.R$ and $X_2 = X_A - \boldsymbol{\theta}.R$ refer figure

The equations $X_A = (X_1 + X_2)/2$ and $\boldsymbol{\theta} = X_1 - X_2/2.R$ gives the displacement of the pulley and the shortening of the pulley. For the set of pulleys following equations are used to calculate resulting displacements of the pulleys driving the fingers refer figure:

$$X_R = (X_1 + X_2)/2, X_L = (X_4 + X_5)/2, X_M = (X_3 + X_L)/2 \text{ and } X_P = (X_R + X_M)/2$$
$$X_P = (2.X_1 + 2.X_2 + 2.X_3 + X_4 + X_5)/8$$

In the FEDERICA hand, X_P is the total shortening of the input tendons is the function of shortening of all five fingers.

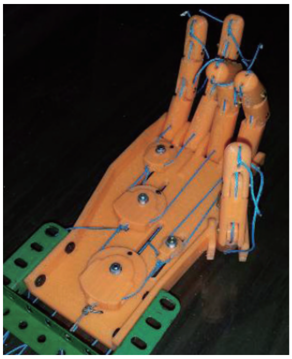

Figure 28: Federica Hand by Carbon et al.

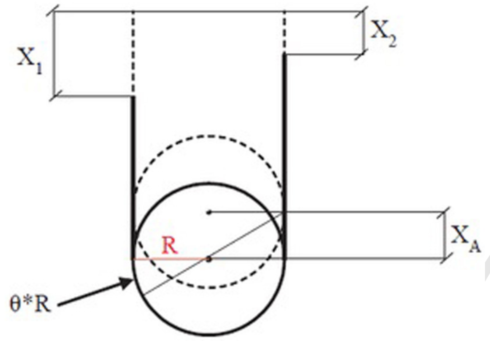

Figure 29: Scheme of Pulley for tendon displacement from initial to final configuration proposed by Carbon et al.

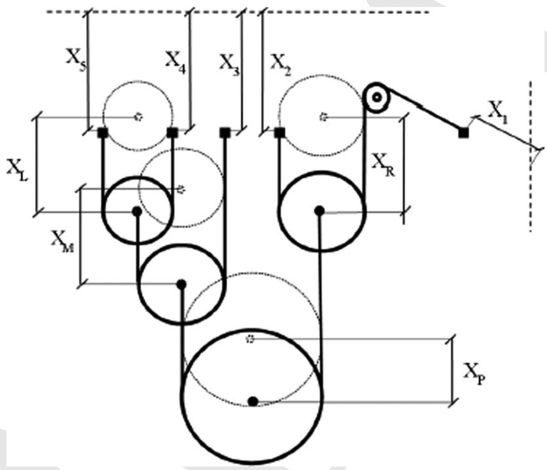

Figure 30: Control Pulley Mechanism of Federica Hand Carbon et al.

The LARM Hand IV prototype is composed of three fingers and a palm. The actuation system consisted three DC motors with a planetary reduction gear train on each finger. A DC motor is rigidly connected to the finger frame to make a finger module.

In LARM hand each finger is composed of two four bar linkage mechanism a_1, c_1, b_1, d_1 and a_2, c_2, b_2, d_2. The first phalanx (ternary link b_1 with sides b,c,d) is the input bar of the first four bar mechanism and also the base frame of the second four bar mechanism. The second phalanx (ternary link c_2 with sides f,g,h) is the input

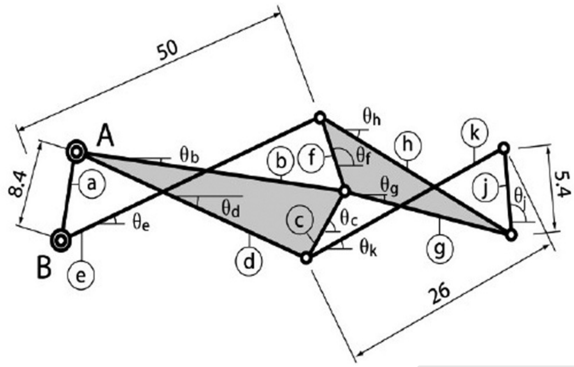

Figure 31: LARM hand proposed by Carbone et al.

for the second four bar mechanism. The third phalanx is the coupler of the second four bar mechanism. The dimensional synthesis is however not disclosed by the authors in this paper. They have determined the angular velocities of the second and the phalanx.

Burck, Zeher, Armiger and Beaty (2009) DARPA Johns Hopkins University Applied Physics Laboratory (APL) is a leading worldwide team which included government agencies, universities, and private companies whose mission was to develop a prosthetic arm that far exceeds any prosthetic available today. The final version of the arm will have control algorithms driven by neural inputs that enable the wearer to move with the speed, dexterity, and force of a real arm. Advanced sensory feedback technologies will enable the perception of physical inputs, such as pressure, force and temperature. The two prototype limbs developed for the Defense Advanced Research Projects Agency (DARPA) program used Targeted muscle reinnervation, a technique pioneered by Dr. Todd Kuiken of the Rehabilitation Institute of Chicago. This technique involves the transfer of residual nerves from an amputated limb to unused muscle regions near the injury. In a clinical evaluation, the first prototype enabled a patient to complete a variety of functional tasks, including pulling a credit card from a pocket. No information on mechanism design and mathematical modeling.

Karnati, Kent and Engeberg (2013) in their work addressed the complex task of unscrewing and screwing objects with a dexterous anthropomorphic robotic hand in two cases with the first finger and thumb and with the little finger and thumb. To develop an anthropomorphic solution, human finger synergies from nine test subjects were recorded while unscrewing and screwing a threaded cap. Human results showed that the periodic motions exhibited by the finger joints shared a common frequency for each subject, but differed in amplitude and phase. They used C6M Motor Hand (Shadow Robot Company, UK) to estimate the forward and inverse Kinematics in generic form which can be applied for any finger and thumb. The Cartesian coordinates for the thumb (x_T, y_T, z_T).

$$
\begin{aligned}
x_T &= \sqrt{2}/2[a_{T1}\{c_{x1x2}(c_{x3x4-}s_{x3}s_{x4}s_{x5}) + s_{x1x2}c_{x5}\}\\
&\quad - a_{T2}[c_{x2}\{s_{x3x4}s_{x5cx3x4}\} - s_{x2cx5}] - a_{T3}[s_{x4sx5} - c_{x4}]]\\
y_T &= a_{T3}s_{x4}c_{x5} + a_{T2}[s_{x2}s_{x5} + c_{x2}s_{x3x4}c_{x5}] + a_{T1}[s_{x1x2}s_{x5+}c_{x1x2}s_{x3x4}c_{x5}] + y_{TH}\\
z_T &= \sqrt{2}/2[a_{T1}\{c_{x1x2}(c_{x3x4} + s_{x3}s_{x4}s_{x5}) - s_{x1x2}c_{x5}\\
&\quad + a_{T2}[c_{x2}\{s_{x3x4}s_{x5+}c_{x3x4}\} - s_{x2cx5}] + a_{T3}[s_{x4}s_{x5} - c_{x4}]]
\end{aligned}
$$

The Cartesian coordinates for the first, middle or ring finger are (x_i, y_i, z_i)

$$
\begin{aligned}
x_i &= a_{i3} + a_{i1a}c_{xi1a}x_{i1b}x_{i2}c_{xi3} + a_{i1b}cx_{i1b}x_{i2}cx_{i3} + a_{i2}c_{xi2cxi3}\\
y_i &= a_{i1a}sx_{i1a}x_{i1b}x_{i2+}a_{i1b}s_{xi1b}x_{i2} + a_{i2}s_{xi2}\\
z_i &= -a_{ia}c_{xi1axi1bxi2}s_{xi3-}a_{i1b}c_{xi1bxi1bxi2}s_{xi3-}a_{i2}c_{xi2}s_{xi3-bi}
\end{aligned}
$$

where $y_{TH} = 8.5$ mm

The Cartesian coordinates for the little finger (x_L, y_L, z_L)

$$
\begin{aligned}
x_L &= a_{L1a}[c_{xLlaxL1bxL2}\Omega_{Lx} - c_\alpha s_{xL1axL1bxL2}S_{xL4}] + a_{L1b}[c_{xL1bxL2}\Omega_{Lx} - c_a s_{xL2}s_{xL4}]\\
&\quad + a_{L3}[s_a^2 + c_a^2 c_{xL4}]\\
y_L &= a_{L1a}[c_\alpha -_{xL3}\, c_{xL1axL1bxL2}s_{xL4} + s_{x1axL1bxL2}c_{xL4}]\\
&\quad + a_{L1b}[c_a -_{xLcxL2}\, s_{L4} + s_{xL1bxL2}c_{xL4}] + a_{L2}[c_{\alpha-xL3cxL2sxL4+sxL2cxL4]+aL3c\alpha sxL4}]\\
z_L &= a_{L1a}[c_{xLlaxL1bxL2}\Omega_{Lz} + s_\alpha s_{xL1axL1bxL2}S_{xL4}] + a_{L1b}[c_{xL1bxL2}\Omega_{Lz} + s_\alpha s_{xL2}s_{xL4}]\\
&\quad + a_{L2}[c_{xL2}\Omega_{Lz} + s_\alpha s_{xL2}s_{xL4}] + aL3[c_\alpha s_\alpha(1 - c_{xL4}] - c\\
\Omega_{Lx} &= (c_\alpha c_{\alpha-xL3}c_{xL4+}s_\alpha s_{\alpha-xL3}),\\
\Omega_{Lz} &= (c_\alpha s_\alpha\, -_{xL3} - c_\alpha s_\alpha - c_\alpha s_{\alpha xL3cxL4})
\end{aligned}
$$

where, $\alpha = 0.96$ rad.

Inverse Kinematics solution presented as:

$$
\begin{aligned}
D &= \{(x_i - x_{iJ2})^2 + (y_i - y_{iJ2})^2 + (z_i - z_{iJ2})^2 - a_{i1}^2 - a_{i2}^2\}/2a_{i1}a_{i2}\\
x_{i1b} &= atan2\{D, \sqrt{(1 - D^2)}\}\\
x_{i2} &= atan2\{\sqrt{[(x_i - x_{iJ2})^2 + (y_i - y_{iJ2})^2]}\} - \alpha tan2(a_{i2} + ai2 + a_{i1}c_{x1b}, (a_{i1}sx_{1b})
\end{aligned}
$$

Chuang and Lee (2011) investigated the conceptual design for the under actuated passively adaptive finger mechanisms for prosthetic c hand or robotic hand application. A systematic approach was conducted for the synthesis of under actuated passively adaptive finger mechanisms. Characteristics of under actuated passively adaptive finger mechanisms were observed from the kinematic concepts, under actuated mechanisms was developed. New mechanisms with three degree-of-freedom and eight links were generated. A computer-aided simulation of the motion for the selected new mechanisms was used for validation of the mathematical model.

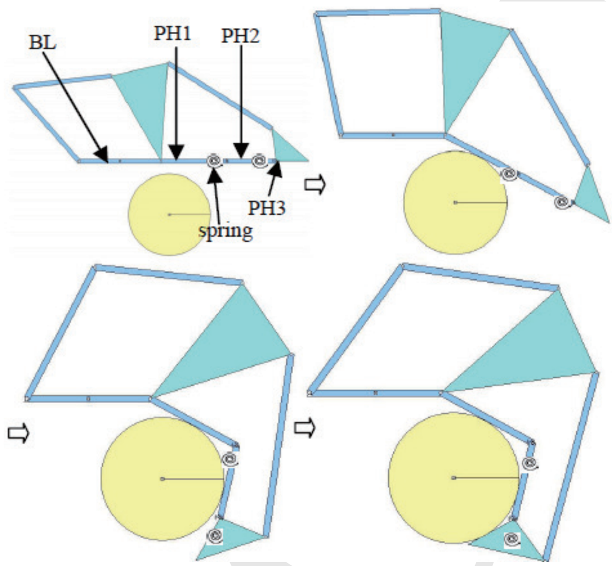

Figure 32: Finger mechanism with revolute input by Chuang and Lee (2011)

To improve the parameters to fit the functional needs of the hand the structural constraints, incremental variations were studied by Markus, Maxime, Gerd and Roland (October 2010), the tests were derived from a set of common grasps as well as some tests performed by surgeons. Using simple cardboard prototypes the kinematics revealed to be a promising and suitable hand kinematics for the DLR Hand Arm System. Refer figure 32.

Ueda, Kondo and Ogasawara (2010a,b) presented the mechanical design of a multi fingered robotic hand referred to as the NAIST hand. Their mechanism required less space for the actuators and reduced the burden on the motors in terms of fingertip force generation. A direct teaching system that involves observation of the contact points between the operator's fingertips and the instrumented object has been successfully implemented to reproduce dextrous in-hand manipulation using the NAIST hand. Human fingers are required to perform various mechanical functions to hold, grasp, pick, press, it's not only up to the extent of designing an adaptive hand which has a capability to mimic the displacement of the links representing the

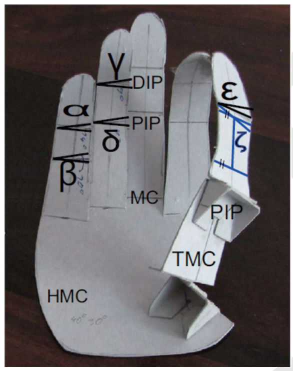

Figure 33: Joints and varied parameters by Grebenstein Markus et al.

inter phalangeal joints.

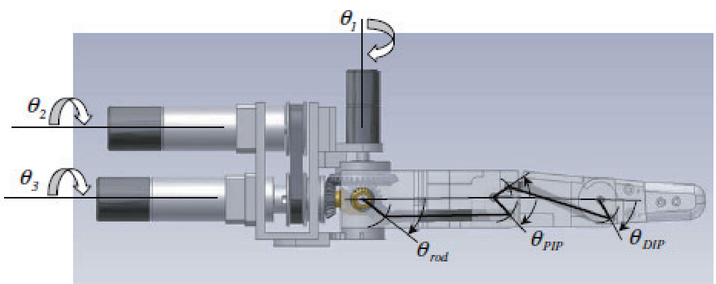

Figure 34: Coupling link Mechanism by Jun Ueda et al.

The finger Kinematics computed for fitted curves are given by:

$$\theta_{PIP} = 0.182\theta_{rad}^2 + 0.835\theta_{rad} + 0.042,$$
$$\theta_{DIP} = -0.137\theta_{PIP}^2 + 1.095_{PIP} - 0.0454$$

Luo, Carbone and Ceccarelli (2008) presented design considerations for improving the grasping capabilities of a low-cost easy-operation three-finger robotic hand. A special planetary gear mechanism was designed for adjusting the position and orientation of the two fingers in robotic hand. This solution significantly improved the flexibility of a robotic hand in terms of size and shape of the objects that can be grasped. Refer Figure 37.

A very simple and landmarked contribution was given by Dechev, Cleghorn and Naumann (1999, 2001) to the designers working on adaptive gripping using simple

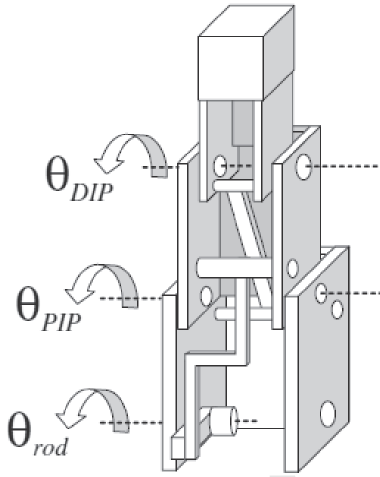

Figure 35: Joint angles in coupling link Mechanism by Jun Ueda et al.

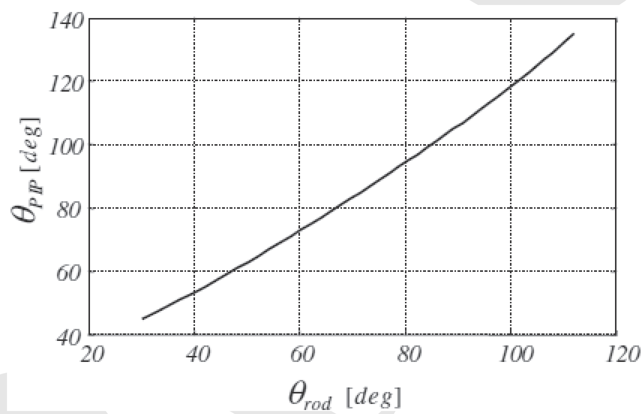

Figure 36: MP and PIP angles, Jun Ueda et al.

linkage mechanism, reducing the number of actuators and the problems due to pulley drive system. Refer Figure 38.

Haulin, Lakis and Vinet (2001); Haulin and Vinet (2003) They carried optimal synthesis of the planer four bar mechanism used in the prosthetic arm. A multi objective optimization of hand prosthesis four-bar mechanisms was performed with reference to seven positions and with respect to five design criteria. Optimum dimensions were first obtained assuming there are no dimensional tolerances or clearances. Considering mechanical error due to manufacturing imprecision optimum

Figure 37: Grasp taxonomy of Human Hand by Luo et al.

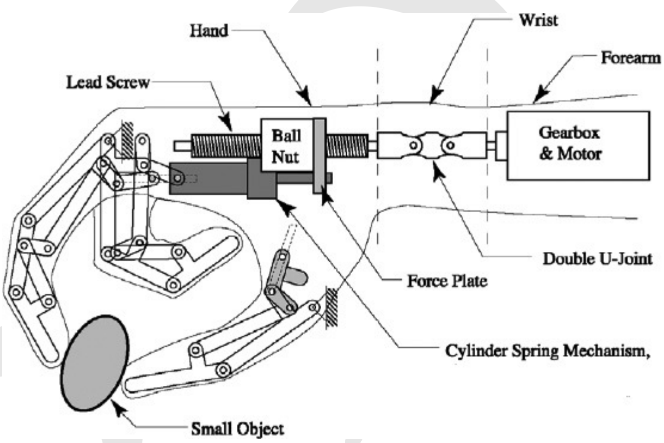

Figure 38: Four Bar Under actuated Mechanism (Figure Curtsey Dechev at el).

values of both tolerances and clearances were then obtained. They showed that the inclusion of drive systems in the optimization of mechanisms can significantly increase the transmission angle, the mechanical advantage and reduce angular accelerations and optimal values of maximum driving torque. Refer figure 39.

Wu, Carbone and Ceccarelli (2009) developed a finger mechanism with one active degree of freedom for an under actuated operation. They verified the feasibility of

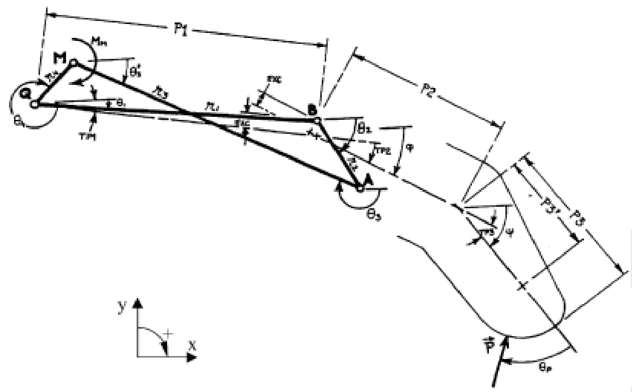

Figure 39: Four Link Mechanism used by Ngale Haulin et al.

the mechanism through suitable kinematic and static analysis to give performance characteristics. Refer figure 40.

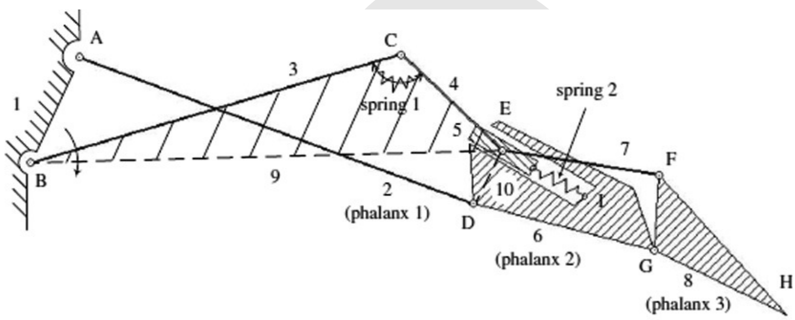

Figure 40: Kinematic Design of 1-DOF finger mechanism proposed by Wu LiCheng et al.

Chang, Tseng and Wu (2004) In their paper presented an auxiliary methodology called the creative mechanism design was introduced into the innovation of gripping devices for prosthetic hands. An existing gripping device (Teh Lin ATG-5F prosthetic hand) constructed by a planar six-bar linkage with one degree of freedom was dealt with by using this methodology. Through the processes of generalization, number synthesis, specialization and particularization for the existing design, five new mechanisms were created for anthropomorphic prosthetic hands. The results showed that the methodology for creative mechanism design as a powerful tool for creating new categories of mechanisms to avoid existing designs that have patent protection and can help designers in the conceptual phase.

Rodríguez, Carbone and Ceccarelli (2006a) formulated the design of a finger driving mechanism as a multi-objective optimization problem by using evaluation criteria for fundamental characteristics regarding with finger motion, grasping equilibrium and force transmission 32 with soft finger pads. Refer figure 41.

Figure 41: Three-fingered 1-D.O.F LARM hand by Marco Ceccarelli et al.

Laliberté and Gosselin (1998); Laliberté, Birglen and Gosselin (2002) studied various under actuated gripper mechanism as end effector for a robot they evaluated the static analysis of the fingers and discussed the control issues of the gripper. Sheng, Hua, Zhang and Zhu (2014) proposed an under actuated prosthetic finger with a compliant driving mechanism based on linkage mechanism and spring elements,. The feasibility of the mechanism was verified through suitable kinematic and static analysis. Moon (2007) presented contact aided finger compliant mechanism for a human finger motion. Their finger mechanism mimics human finger motion with contact aided compliant mechanisms. The motion mimicking was done through linkage synthesis theories and was converted to a compliant mechanism to reduce the number of actuators and to achieve compactness.

Mu and Huang (2007) proposed a three degree-of-freedom parallel finger mechanism the forward solution and inverse solution of the finger mechanism were obtained. Refer figure 42.

Birglen and Gosselin (2006) presented a new technique to analyze the grasp stability of two phalanx under actuated fingers using a grasp-state plane approach. Castro, Arjunan and Kumar (2015) presented a coupled and directly self-adaptive (CDSA) under actuated grasp mode which can achieve coupled grasp and simultaneously directly self-adaptive grasp.

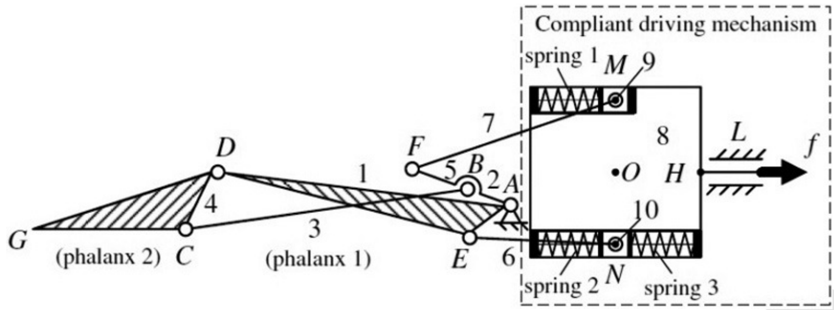

Figure 42: Under actuated prosthetic figure by Mu Dejun et al.

Wells and Greig (2001) studied characterizing human hand capabilities or demand created by various occupational tasks or activities of daily living by measuring the maximum force exerted on a force dynamometer in a number of standard grips. A framework was proposed to characterize human hand prehensile strength in generic form by describing external force and moment wrench capability, where a wrench a vector describing the forces and moments applied at a point.

Kondo, Ueda and Ogasawara (2008) proposed a method for recognizing in-hand manipulation of the operator by observing a contact state transition between an object and the human hand. An instrumented object with a pressure distribution sensor and a position orientation sensor was developed. The validity of the proposed method was confirmed by experiments. Refer figure 43.

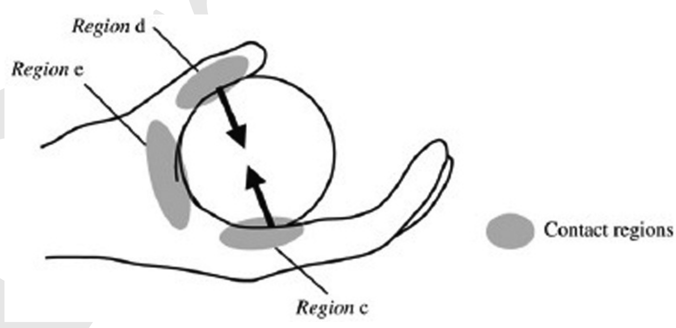

Figure 43: Contact state holding a Cylindrical object explained by Masahiro Kondo et al.

Ciocarlie, Lackner and Allen (2007) They presented a method for building analytical contact models for soft fingers. The friction contacts were derived based on general expressions for non planar contacts of elastic bodies considering local geometry and structure of the objects in contact. These constraints were then formulated as a linear complementarity problem, the solution of which provided the normal and frictional forces applied at each contact as well the relative velocity of the bodies involved. This approach captured frictional effects such as coupling between tangential force and frictional torque, They illustrated the method by analyzing manipulation tasks performed by an anthropomorphic robotic hand quipped with soft finger pads. Refer figure 44.

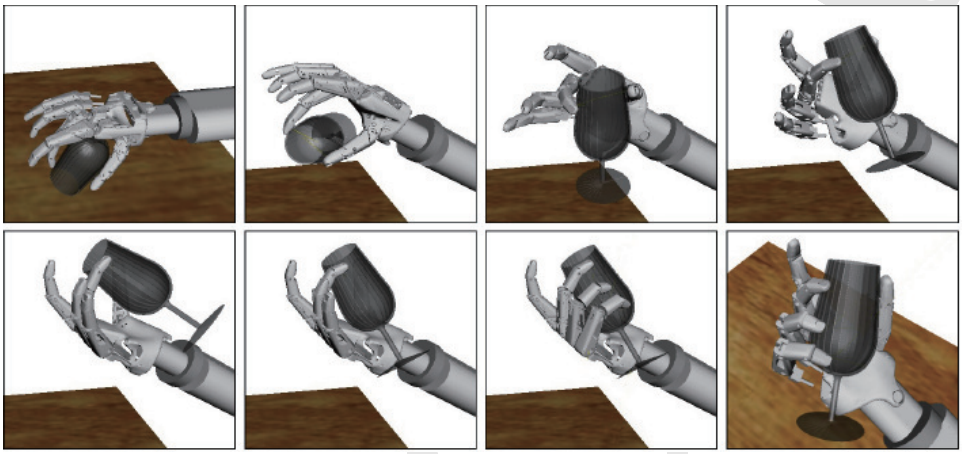

Figure 44: Simulation of a manipulation task using an anthromorphic robotic hand by Ciocarlie Matei et al.

Mattar (2013) studied to find out the state of the art on dexterous robotics end-effectors hands, his review finds biomimetic approaches using a framework that permits for a common description of biological and technical based hand manipulation behavior.

Kurita, Ono, Ikeda and Ogasawara (2011) proposed a human-sized multi-fingered robot hand with detachable mechanism at the wrist. The fingers designed were tendon-driven by wires and the actuators embedded in the arm part. The driving forces from the arm part were transmitted to the hand part by a gear mechanism at the wrist, as shown in the Figure 45.

Carrozza, Massa, Micera, Lazzarini, Zecca and Dario (2002) developed a novel prosthetic hand based on a bio-mechatronic design. The proposed hand was designed to augment the dexterity of traditional prosthetic hands while maintaining approximately the same dimension and weight. They aimed at providing enhanced grasping capabilities and a sensory-motor coordination to the amputee, by integrating miniature mechanisms, sensors, actuators, and embedded control. A bio-

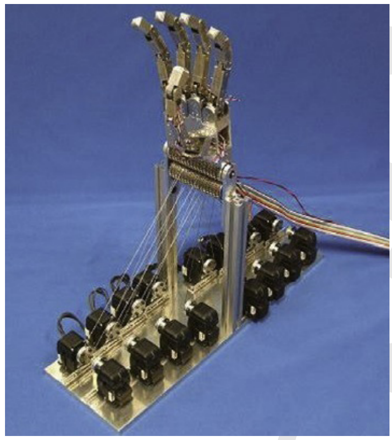

Figure 45: Robot hand system proposed by Yuichi Kurita et al.

mechatronic hand prototype with three fingers and a total of six independent DOFs were designed and fabricated. Their paper focused on the actuators system, which was based on miniature electromagnetic motors.

Razo and Morales Sanchez (2013) Their work presented the dimensional synthesis for a mechanical finger, based in four bar mechanisms, by satisfying the anthropometric and kinematic constrictions of the human finger. The basic criteria used for the dimensional synthesis was the maximum rotation angle for each phalanx, so a human like motion may be achieved. The syntheses of each finger was obtained using Freudenstein's methodology, assuming that the links lengths are constant. The only variable which may modify the displacement behavior of the system is the coupler, for each four bar mechanism, therefore its length is directly related to the position of the finger.

Rodríguez, Carbone and Ceccarelli (2006b) Design of driving mechanisms for fingers was carried out at LARM in Cassino with the aim to obtain one degree of freedom actuation for an anthropomorphic finger. The dimensional design of a finger driving mechanism was formulated as a multi-objective optimization problem by using evaluation criteria for fundamental characteristics that are associated with finger motion, grasping equilibrium and force transmission. The feasibility of the herein proposed optimum design procedure for a finger driving mechanism tested by numerical examples used to enhance a built prototype of a three-fingered hand.

Yang, Pitarch, Abdel-Malek, Patrick and Lindkvist (2004) aimed to develop a five-fingered with 15 joint EMG controlled robot anthropomorphic hand. They named the hand as AR hand with each finger consisting of three phalanxes and three joints.

The under actuation design was based on the multiple four bar mechanism. The motion to the finger was provided by three embedded motors, one motor for the actuation of the little, ring and middle fingers, one for index and one for the thumb. No details about the synthesis of mechanism revealed in the paper. Refer figure 46.

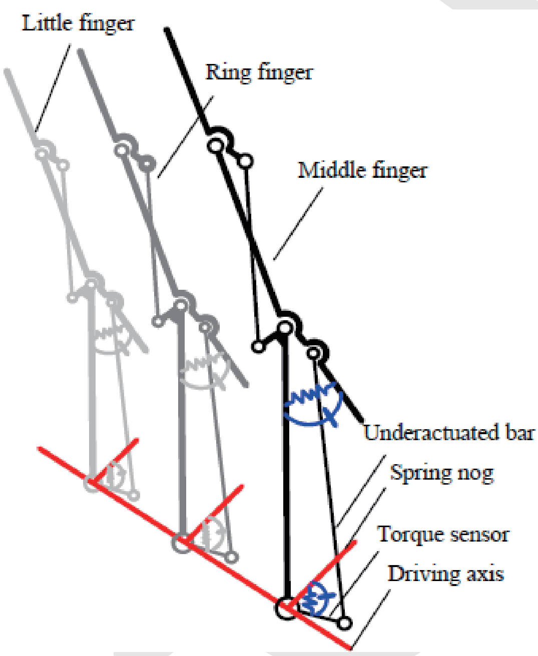

Figure 46: Under actuated Mechanism by Jingzhou Yang et al.

Liu, Meusel, Seitz, Willberg, Hirzinger, Jin, Liu, Wei and Xie (2007) presented hardware and software architecture of the new developed compact multisensory DLR-HIT hand. The hand with four identical fingers and an extra degree of freedom for palm. In order to achieve high modularity and reliability of the hand, a fully mechatronic integration and analog signals philosophy were implemented to minimize the dimension, number of the cables (five cables including power supply) and protect data communication from outside disturbances. Refer figure 47.

Takahashi, Tsuboi, Kishida, Kawanami, Shimizu, Iribe, Fukushima and Fujita (2008) proposed a new robust force and position control method for property-unknown objects grasping. The control method was capable of selecting the force control or position control, smooth and quick switching according to the amount of the external force. The proposed method was applied to adaptive grasping by three-fingered hand which has 12 DOF. In addition a new algorithm determined the grasp force

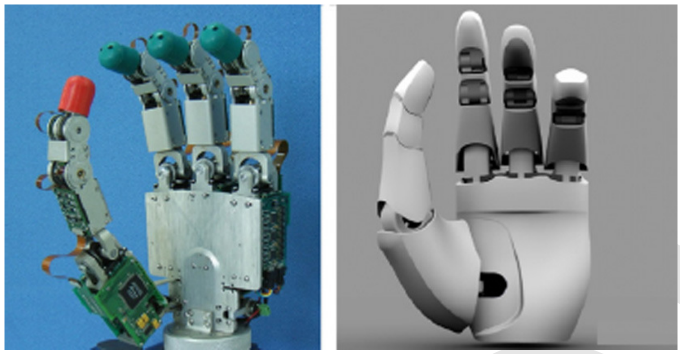

Figure 47: DLR HIT hand H. Liu et al.

according to the “slip” measured with the tactile sensor and the visco elastic media on the fingertip. This algorithm worked at starting and stationary state, so the friction and mass unknown object grasping was realized by the effectual force.

6.1 Controlling a Prosthetic arm using EMG

Automation required to control a prosthetic hand is the major feature of interest for any user. Prosthetic arm has evolved from stages from Body Powered to automation. This section covers a review on the work done by the researchers and scientists to develop a control system for the prosthetic arm.

Huang, Englehart, Hudgins and Chan (2005) This paper introduces and evaluates the use of Gaussian mixture models (GMMs) for multiple limb motion classification using continuous myoelectric signals. The focus of this work is to optimize the configuration of this classification scheme. To that end, a complete experimental evaluation of this system is conducted on a 12 subject database. The experiments examine the GMMs algorithmic issues including the model order selection and variance limiting, the segmentation of the data, and various feature sets including time-domain features and Auto regressive features. The benefits of post processing the results using a majority vote rule are demonstrated. The performance of the GMM is compared to three commonly used classifiers: a linear discriminant analysis, a linear perceptron network, and a multilayer perceptron neural network. The GMM-based limb motion classification system demonstrates exceptional classification accuracy and results in a robust method of motion classification with low computational load.

Chan and Englehart (2005) investigated dexterous and natural control of upper extremity prostheses using the myoelectric signal. Their scheme described hidden Markov model (HMM) to process four channels of myoelectric signal, with the task of discriminating six classes of limb movement. They concluded that HMM - based approach described demonstrated considerable promise in multifunction myoelectric control. It is capable of higher classification accuracy than that demonstrated in their previous work and its low computational complexity makes it an attractive choice in a real-time embedded system.

Yang, Zhao, Gu, Wang, Li, Jiang, Liu, Huang and Zhao (2009) For the EMG control, they proposed two specific methods, the three-fingered hand gesture configuration of the hand and a pattern classification method of EMG signals based on a statistical learning algorithm. They recognized eighteen active hand gestures of a subject which can be directly mapped into the motions of the hand. Refer figure 46.

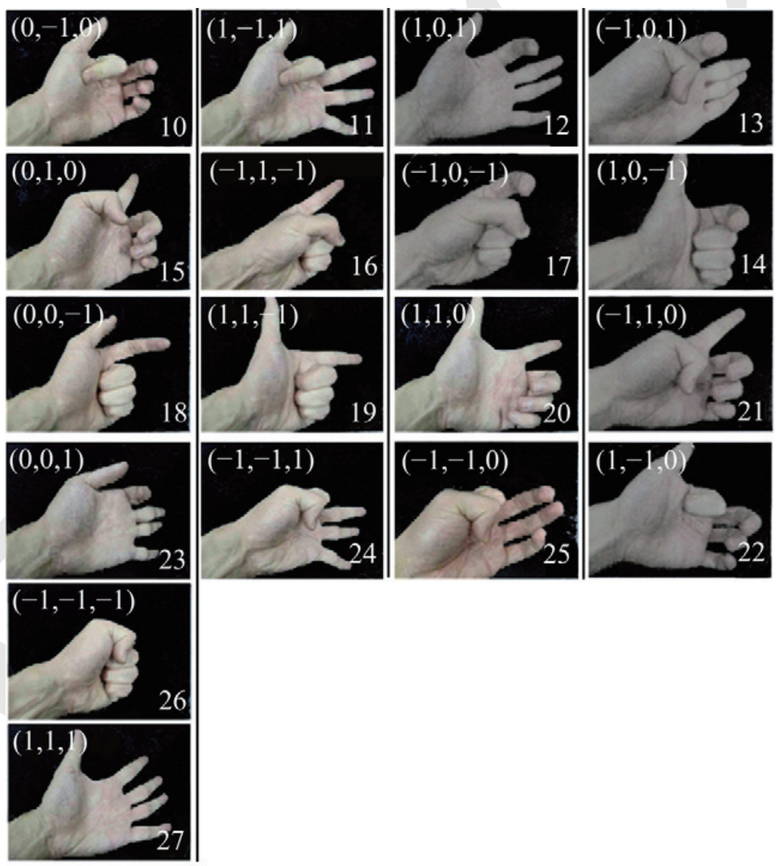

Figure 48: Hand gestures ranked in order of performing difficulty Da-Peng Yang et al.

Bitzer and Van Der Smagt (2006) introduced a method based on support vector machines which can detect opening and closing actions of the human thumb, index finger, and other fingers recorded via surface EMG. They claim this method is ideally suited for the control of active prosthesis with a high number of active degrees of freedom. They demonstrated on a robotic four-finger hand and can be used to grasp objects.

Ortiz-Catalan, Brånemark, Håkansson and Delbeke (2012) described several implantable electrodes as a solution for the natural control of artificial limbs and the control over limb movement analogous to a physiological system. After scrutinizing different electrode designs and their clinical implementation, they concluded that the epimysial and cuff electrodes are able to get long-term stable and natural control of robotic prosthetics. Figure 47 shows epimysial electrode.

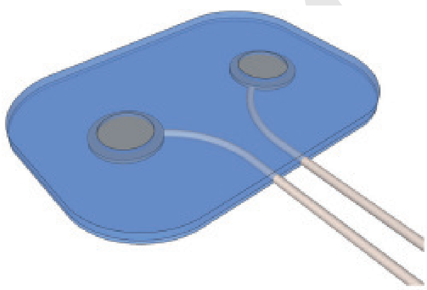

Figure 49: A Bipolar Epimysial electrode Max Ortiz Catalan et al.

Ehrsson, Rosén, Stockselius, Ragnö, Köhler and Lundborg (2008) worked on how upper limb amputees can be made to experience a rubber hand as part of their own body. Their findings outline a simple method for transferring tactile sensations from the stump to a prosthetic limb by tricking the brain, to develop artificial limbs that feel like real part of the body.

Fukuda, Tsuji, Kaneko and Otsuka (2003) proposed a human-assisting manipulator tele operated by electromyographic signals and arm motions as depicted in the Figure 6. They claimed their method can realize a new master–slave manipulator system that uses no mechanical master controller. The control system consists of a hand and wrist control part and an arm control part. The hand and wrist control part selects an active joint in the manipulator's end-effector and controls it based on EMG pattern discrimination. Their experiments showed that the developed system could learn and estimate the operator's intended motions with a high degree of accuracy using the EMG signals, and that the manipulator could be controlled smoothly. They also confirmed that their system could assist the amputee in performing desktop work. Figure 48 shows the flow of control system.

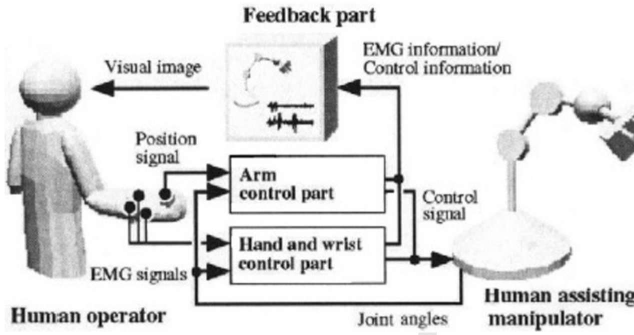

Figure 50: Control System Osamu Fukuda et al.

Castro, Arjunan and Kumar (2015) Their study observed that a sub-set of the hand gestures have to be selected for an accurate automated hand gesture recognition, and reports a method to select these gestures to maximize the sensitivity and specificity. Experiments were conducted where sEMG was recorded from the muscles of the forearm while subjects performed hand gestures and then was classified offline. The performances of ten gestures were ranked using the proposed Positive–Negative Performance Measurement Index (PNM), generated by a series of confusion matrices. When using all the ten gestures, the sensitivity and specificity was 80.0% and 97.8%. After ranking the gestures using the PNM, six gestures were selected and these gave sensitivity and specificity greater than 95% (96.5% and 99.3%); Hand open, Hand close, Little finger flexion, Ring finger flexion, Middle finger flexion and Thumb flexion. Conclusion: This work has shown that reliable myoelectric based human computer interface systems require careful selection of the gestures that have to be recognized and without such selection, the reliability is poor.

Kuiken, Miller, Lipschutz, Lock, Stubblefield, Marasco, Zhou and Dumanian (2007) developed a technique that used nerve transfers to muscle to develop new electro myogram control signals and nerve transfers to skin, to provide a pathway for cutaneous sensory feedback to the missing hand. They did targeted reinnervation surgery on a woman with a left arm amputation at the humeral neck. The patient described the control as intuitive, she thought about using her hand or elbow and the prosthesis responded appropriately. This surgery showed improved prosthetic function and ease of use in this patient. Figure 47, presents targeted sensory reinnervation

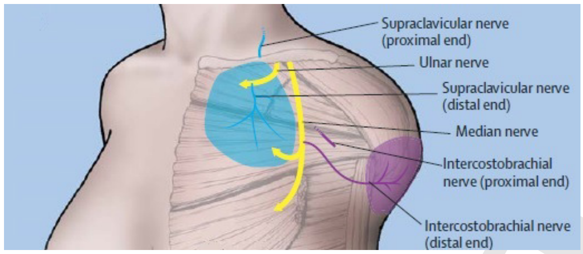

Figure 51: Targeted sensory reinnervation by Todd A Kuiken et al.

Miguelez (2002) explained the design theory related to prosthetic rehabilitation considering volume containment, suspension, comfort, range of motion, component consideration, stabilization, anatomical contouring and aesthetics. He studied the control system using the myo electric controlled upper limb prosthesis. Peleg, Braiman, Yom-Tov and Inbar (2002) proposed using the electro myo graphic signals recorded by two pairs of electrodes placed over the arm for operating such prosthesis. Multiple features from these signals are extracted when the most relevant features are selected by a genetic algorithm as inputs for a simple classifier. They claim this method results in a probability of error of less than 2%.

Razak, Osman, Gholizadeh and Ali (2014) developed a prosthesis system known as bio mechatronics wrist prosthesis. The prosthesis system was implemented by replacing the bowden tension cable of body powered prosthesis system using two ultrasonic sensors, two servo motors and microcontroller inside the prosthesis hand for trans radial user. Figure 50 illustrates the set up.

Figure 52: Controlling Prosthesis using Ultra sonic sensor by Razak et al.

Ueda, Kondo and Ogasawara (2010b) studied investigating the use of forearm surface electro myo-graphic (EMG) signals for real time control of a robotic arm, figure 51 demonstrates EMG signal.

Velliste, Perel, Spalding, Whitford and Schwartz (2008) explained that the arm movement may be well represented in populations of neurons recorded from the motor cortex. They described a system that permits embodied prosthetic control, have showed how monkeys use their motor cortical activity to control a mechanized arm replica in a self-feeding task. Their study also evaluated the require degree of detection for the input of the ultrasonic sensor to generate the wrist movements.

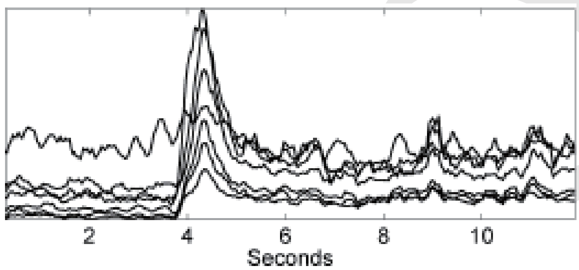

Figure 53: EMG Signals Pradeep Shenoy et al.

Ortiz-Catalan, Brånemark, Håkansson and Delbeke (2012) reviewed several implantable electrodes and discussed them as a solution for the natural control of artificial limbs, producing control over limb movement analogous to that of an intact physiological system. This includes coordinated and simultaneous movements of different degrees of freedom. It was found the input signals must come from nerves or muscles that were originally meant to produce the intended movement and the feedback is perceived as originating in the missing limb without requiring burdensome levels of concentration. After scrutinizing different electrode designs and their clinical implementation, they concluded that the epimysial and cuff electrodes can impart long-term stable and natural control of robotic prosthetics, provided that communication from the electrodes to the outside of the body is guaranteed.

Neogi, Mukherjee, Ghosal, Das and Tibarewala (2011) They highlighted the hardware design technique of a prosthetic arm with implementation of gear motor control aspect. The prosthetic control arm movement was demonstrated applying processor programming and with the successful testing of the designed prosthetic model. The architectural design of the prosthetic arm was replaced by lighter material instead of heavy metal, as well as the traditional EMG (electro-myographic) signal was replaced by the muscle strain.

Su, Fisher, Wolczowski, Bell, Burn and Gao (2007) They proposed a novel method of using electro myo graphic (EMG) potentials generated by the fore arm muscles during hand and finger movements to control an artificial prosthetic hand worn by an amputee. Surface EMG sensors were used to record the forearm EMG potential signal via a PC soundcard. They used a 3D electromagnetic positioning system together with a data-glove mounted with 11 miniature electromagnetic sensors to acquire human hand motion in real time. The synchronized measurement of hand posture and EMG signal stored as prototypes, in the format of a series of data frames, each comprising a set of positional and orientation posture data and a set of EMG data. A graphical hand model was also generated to visualize the real time hand movement. EMG measurement device was attached to the forearm muscle of the prosthetic hand user. Candidate sets of EMG data acquired in real time was compared with stored prototypes within each data frame using a pattern recognition approach. The most likely posture data set in this frame was to be considered as the numerical expression of the current hand shape and used to control a robotic hand to carry out the user's desire. Using two-channel EMG measurement device they first applied frequency analysis on the conditioned raw EMG signal. Then, pattern recognition techniques were applied to identify the most closely aligned spectrum generated from the data recorded by the dual channel EMG measurement device. They claimed that this approach has several advantages over existing methods, simplify the classification procedure, saving computational time, will reduce the requirement for the optimization process and finally it will increase the number of recognizable hand shapes subsequently improving the dexterity of the prosthetic hand and the quality of life for amputees.

Geng, Yu, You and Li (2010) investigated the performance of EMG pattern recognition in classifying eight functional movements plus a "no movement" task. Four kinds of EMG feature sets, time-domain (TD) features, auto-regression (AR) model features, combination of TD and AR features, and wavelet packet coefficients, were used to represent the EMG patterns, respectively. Using a linear discriminant analysis classifier, the TD features o across four able-bodied subjects was greater than 94%. The average classification accuracy of all 8-channel EMG combinations could achieve more than 90%. The results suggested that it is feasible to use EMG pattern recognition for the classification of functional movements.

7 Summary & Conclusion

The study of the papers gives a lead to understand the various methodologies and mathematical algorithms which can be used to achieve a mechanism to perform desired motion for a prosthetic arm. Researchers have modeled the grasping forces, velocities of a gripper, arm convex, concave trajectories to reach the object, relations with the degree of freedom and established with the lab prototypes. The simple motions like holding of an object to complex one that is screwing and unscrewing of the parts were also analyzed. The pick and place mechanism are becoming obsolete, these grippers may fail to decide the amount of the gripping force required for holding specific object. The selection of type synthesis is important, problems in using the pulley mechanism in an adaptive grasping is said to be solved using linkage mechanisms due to functional reliability of the same. As studied in the NAIST, DLR, LARM-projects adaptive gripping is the next level of the development in upper limb prosthesis. The applications may be used in humanoid, medical equipment and industrial applications as well. Development of the prosthesis from cable harness actuated mechanism to electrical actuators controlled by myo electric signals sensed from human body makes them smart but not intelligent. The myo electrically controlled prosthesis may suit to a segment of the patients but involves complexity as far as maintenance is concerned. The EMG sensors have their limitations while those are places on the muscles of working side of human body. The signal may loosen its strength due to aging and atmospheric conditions. This also requires the proper training of the muscles to get desired function actuated in the prosthesis. People having active and healthy stump muscles can respond well to the EMG signals. Miniaturization making each finger to be operated individually using efficient actuators. User interface to control the device is still an area which requires more research. With user controlling and interfacing has to be designed with feedback and the command signal. Near natural control of the robotic hand are based on the bioelectric signals from the brain or the muscles. Brain controlled devices becomes an option for the people who may be have lost control of all their muscles. Surface electroencephalogram sensing is still in the nascent stage of development and the implantable devices are requires surgery and expert monitoring. Some researchers qualified the experiments but conversion of the technology to the practical deployment appears to be complicated. In conclusion it can be interpreted that there is a wide scope in design in an adaptive mechanism for opening and closing of the fingers using other methods of path and position synthesis. Simple mechanisms and less parts may optimize the cost factor. Reduction in the weight of the prosthesis may be achieved using polymers used for engineering applications. Control system will remain never ending challenge for the researchers, but it is essential to maintain the simplicity from the patient's perspective.

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