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Kinematics of human hand and robotics applications

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Abstract

Human kinematics is very vital to robotics study as it plays a major role in robotic development and advancement. The importance of robotics study and applications in this current era cannot be over emphasized. This paper looks at the human hand kinematics, taking cognizance of the important elements of joint types and number of joints in the human arm, with emphasis on the degree of freedom for mobility purposes. It has highlighted the multi-various capabilities of the human hand and also indicated the limitations, thus throwing more light on the possibility of maximizing these limitations and improving on the mobility and capabilities of the human hand, where new tasks and functions can be defined and robots designed and directed to carry out such functions so as to improve the productivity of its applications in various areas of Engineering. In the light of the above a new direction of research in new tasks definitions and functions are clearly opened.

Keywords: Kinematics; Human hand; Robotics; Grasping; Joint; Mobility; Degree of freedom

1. Introduction

The human hand is the primary part of the body that facilitates handling and manipulation of objects of various shapes and sizes. Simple as it may look, this part of the body is highly sophisticated. It comprises twenty-seven (27) bones [1]. The wrist, palm and five fingers are the three main parts of the hand. Eight (8) small bones form the wrist. These bones are called carpals. They connect forearm bones to the hand. The forearm bones are called the ulna and radius. Metacarpals are five (5) bones that make up the palm. These link the fingers and the thumb to the wrist. Carpometacarpal (CMC) joints are joints that exist between the wrist and finger metacarpals. On the other hand, the joint linking the thumb metacarpal to the wrist is called radiocarpal (RC) joint [2].

There are three (3) long bones on each finger; these are called phalanges. On basis of their distance to the palm, they are named proximal, middle and distal phalanges. All the phalanges are linked to one another via interphalangeal joints except the proximal phalanx (PP) – which is connected to the metacarpal bone through the metacarpophalangeal (MCP) joint. Proximal interphalangeal (PIP) joint is the joint between the proximal and middle phalanx. Lastly, the distal interphalangeal (DIP) joint is the closest joint to the end of the finger [2]. Analysis of the kinematics of the human hand show the relative movement between these bones at the joints. Figure 1 shows a labelled skeleton of the human hand.

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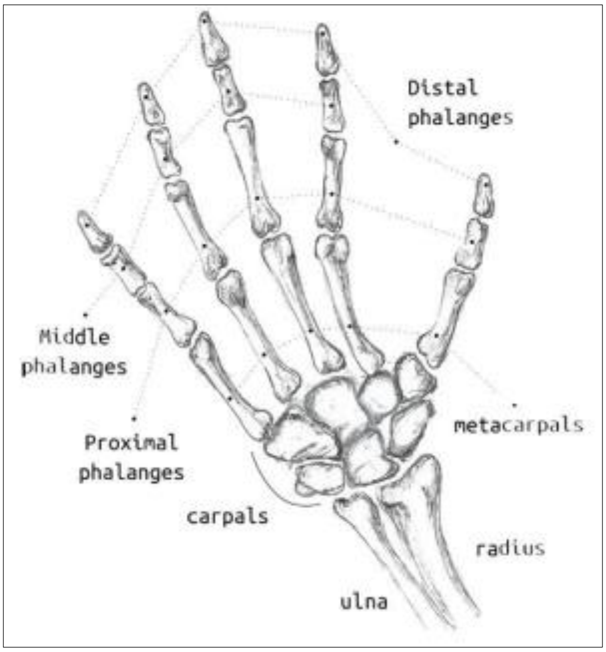


Figure 1 Skeleton of the Human [2]

[2] notes that the joints on the human hand are classified as hinge, saddle and condyloid joints. The hinge joints have one (1) degree of freedom (DoF), whereas the saddle and condyloid joints have two (2) degrees of freedom. The CMC, PIP and DIP joints are hinge joints – they only permit movement toward and away from the palm. According to [3], the Vitruvian man's hand study conducted show that the fingertips of the human hand lie approximately on a common circle when abducted. For precision grip and holding objects firmly, the thumb finger can turn to oppose the other four fingers. Every finger on the human hand is so designed to assist the overall hand's function; this concept is adapted for robotic hands. Human-inspired robots have been developed in the past decades with varying amounts of sophistication. The DoFs and number of joints selected for such robots depend on the task for which the robot is designed [2]. The Shadow Dextrous Hand for instance, has 20 DoFs and 24 movements. This greatly improves flexibility of the robotic hand in grasping and manipulating a wide range of objects. Each finger is designed to move independently. It uses a total of 129 sensors to enhance high-level precision and accuracy [4].Figure 2 shows the shadow of human kinematics.

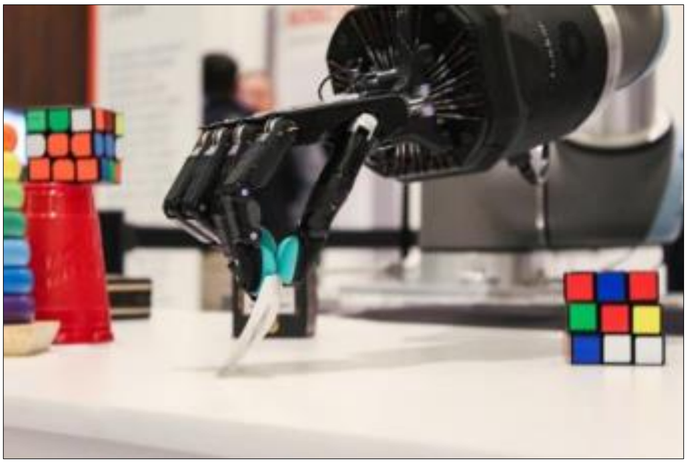


Figure 2 The Shadow Hand [4]

The kinematics of robotic hands increase in complexity depending on the function(s) for which it is designed. Robotic hands designed for grasping only are not as complex as those required for manipulating objects or making gestures. Robotic hands designed specifically for grasping require less DOFs. Such hands have all finger joints coupled. Also, the thumb and base motion is coupled with the CMC joint of the little finger. Robots that require both manipulation and grasp usually implement some compromise. Such compromise is usually a trade-off between complexity of the controls and hand motion capabilities. Although the hand performance depends strictly on the thumb dexterity and opposability, human-inspired robots are not designed on basis of the finger- thumb interaction. The thumb capabilities are largely determined by its base placement and kinematics [2]

Several researches have been carried out to understand the human hand mechanics. Rehabilitation of the upper arm and hand function has already benefitted from the product of such research endeavours[5].Prosthetic hands such as that shown in Figure 1 is a myoelectric bionoic arm. Such arms work by using signals from the user's muscles in form of small electrical signals generated naturally by the wearer. The signals are converted into "Intuitive and proportional bionic hand movement"[6].

Figure 3 Bionic Arm showing Effective Kinematic Mimicry of the Human Hand [6]

A typical industrial application of robots that mimic the human hand is the Robonaut Hand of NASA. Since 1996, NASA began working on the Robonaut project. The first version, Robonaut 1 has shown in Figure 4 was produced in 2000. Overtime, engineers have worked on improving Robonaut. It is designed to be capable of using the same tools as an astronaut. The newest version of the robot, named Robonaut 2 or R2, was launched to the International Space Station (ISS) on board Discovery – a US space shuttle in 2011. It was used to take air quality measurements; it could clean the handrails inside the station – thus making it possible for astronauts to focus on more important science and maintenance tasks on board. R2 was also tasked with flipping switches and pushing buttons.

Figure 4 Robonaut Sending its First Tweet[7]

Figure 5 shows a collection of industrial uses of robot hands. In this collection, it is obvious that robot hands have been used in various aspects of human endeavour including underwater exploration, search and rescue, agriculture, social services, domestic services, space exploration, prosthetics [8].

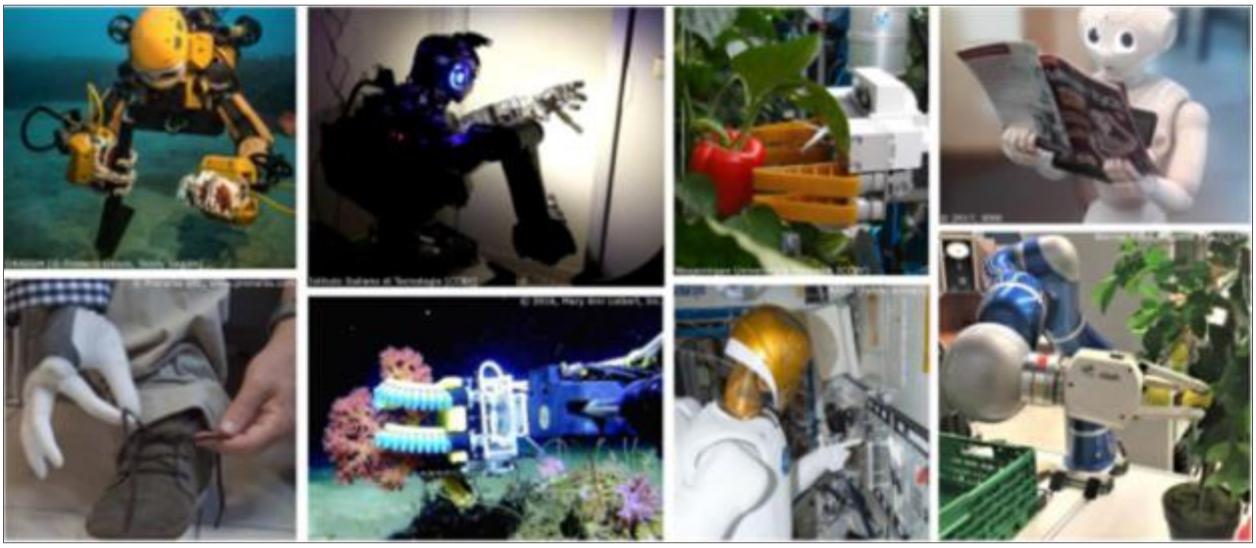


Figure 5 Real-World Applications of Robotic Hands [9][10],[11],[12],[13.]

Most industrial material handling robots have grippers that are specially designed to suit the type and form of materials they transport. However, robots are commonly used to perform tasks that are either too risky for human operation or repetitive with high production rates required. Some manipulative tasks are best carried out by the human hand. To make robots perform such tasks safely and reliably, they must be designed with end effectors that are formed like the human han.

The human hand structure and function has been studied for several decades. Results of such studies have been successfully applied in developing mechanized hands. However, the capability of such hands in reality remains a challenge. Effective handling of objects in unstructured applications and environments make it difficult for articulated mechanized hands to achieve realistic usability. Often a compromise is adopted by hand designers; resulting in robotic end effectors being made for specific purposes. In the industry at present, robotic arms are used in welding, assembly, pick and place, painting, packaging, labelling, inspection, palletizing and testing.

The biomechanics of hand arm is very interesting.Most of the things we do as humans involve the hand. The hand motion involve differentiated movement of the digits. The fingers, and especially the thumb frequently play varied and specific roles to create hand shapes for communicative gesture, environmental exploration, and grasping of all sorts of object – irrespective of geometry, shape or to apply and direct forces for manipulating, moulding, or stabilizing hand-held objects with widely-varying properties including the hardness and weight of such objects. The actions involving the hand are often complemented by arm movements; for instance, in positioning or orienting the hand to give maximum advantage. These are possible in part due to the anatomical structure of the bones of the hand and arm, and the man muscles whose combined contractions flex some joints, extend others and hold yet others in a fixed position

Also very important in hand motion is the neural control systems and the integrative and coordinative structures in the brain and spinal cord. The somatosensory pathways bring information from skin and muscle, allowing subtle gradation of motor output with adjustment, for instance, to cope with changes in the peripheral conditions under which movements are taking place. Vision is also important in anticipatory tailoring of movement parameters to perceived attributes of the object to be manipulated such as shape. Visual cues such as the object's smooth texture, may signal object properties – slippery surface in this case – which, based on previous handling experience, call for different movement strategies.

According to [14], robotic hands should be structured in a similar way to the human hand for them to grasp a target object dexterously. The human hand consists of a thumb, four fingers (index, middle, ring and little finger) all formed on a palm. There are 27 bones in a single hand, as well as muscles, tendons and other structures which are necessary for the hand to function adequately. From each fingertip to the base of the finger, there is a distal phalanx, middle phalanx, and proximal phalanx. The metacarpal bone lies between the base of the fingers and the carpal region. Between the phalanx bone lies joints called the distal interphalangeal (DIP) joint, the proximal interphalangeal (PIP) joint, metacarpophalangeal (MP) joint, and the carpometacarpal (CM) joint. The bones and joints in the human hand are shown in Figure 6.

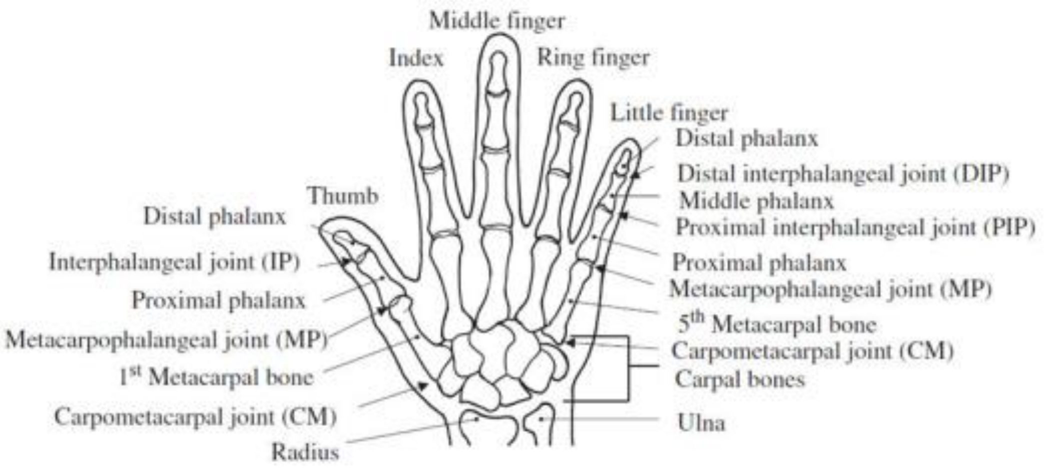
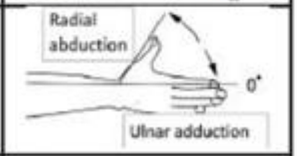
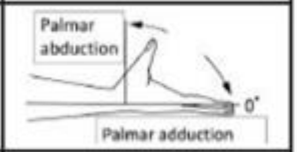
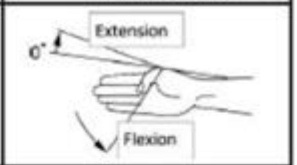
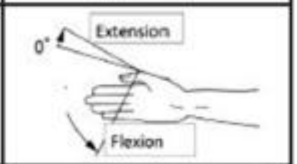
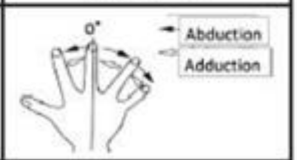
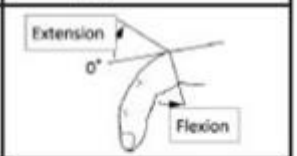
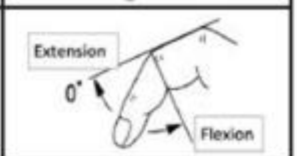
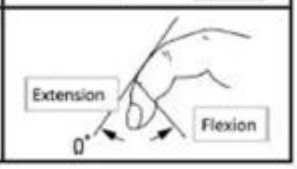


Figure 6 Bones and Joints in the Human [14]

The MP joint has two degrees of freedom (DOFs), adduction/abduction and flexion/extension, along two axes that are approximately orthogonal to each other. DIP and PIP joints have only flexion and extension with a single DOF. In the case of normal movement, the DIP joint moves in conjunction with the PIP joint; therefore the two joints are considered as a single entity with one DOF. Due to its small operating range, the CM joint of the fingers is considered negligible. Based on this, robotic fingers can be modelled with just three DOFs. The thumb has only a distal phalanx and proximal phalanx before the metacarpal bone. The joints between the bones are called (beginning from the fingertip) the interphalangeal (IP) joint, MP joint, and CM joint. The CM joint has two DOFs: flexion/extension and adduction/abduction. This enables the thumb to oppose each finger – called the thumb opposition. The thumb MP joint also has two DOFs in flexion/extension and adduction/abduction; however, it usually is modelled as one DOF of flexion/extension due to limited operating range of adduction/abduction. The flexion/extension of a single DOF is possible for the thumb IP joint. Thus, although the human thumb has five DOFs, from kinematics perspective, modelling four DOFs may be suitable for the purpose of making the robotic hand model simpler. Table 1 shows the movable range of the human.

Table 1 Movable Range of the Human Hand

Name	Motion direction	Movable angle (degree)	Reference drawing
Thumb	Radial abduction Ulnar adduction	60 0	
	Palmar abduction Palmar adduction	90 0	
	MCP flexion MCP extension	60 10	
	IP flexion IP extension	80 10	
Fingers	Abduction Adduction		
	MCP flexion MP extension	90 45	
	PIP flexion PIP extension	100 0	
	DIP flexion DIP extension	80 0	

From Table 1, it can be seen that whereas the radial abduction and ulnar adduction of the thumb are motions in the volar aspect, the palmar abduction and adduction are motions in a plane that is orthogonal to the volar aspect. The carpal region of the palm comprises eight carpal bones. Although the palm of the human hand has multiple DOFs in reality, there is approximately one DOF in the transverse arch of the palm. The human hand comprises five fingers, including the thumb with its distinct shape; this has been specialized to adapt to the environment within which man operates. The human hand has a thumb-finger opposition suitable for grasping and manipulating small objects. Its manipulation capability is greatly enhanced by the opposable thumb feature, as well as the slight curvature of the fingers toward the thumb Q [15].

Grasps can be categorized as: power grasp and precision grasp. When working with a hammer for instance, power grasp is applied. In the process, the fingers clamp down on an object with the thumb – creating a counter pressure. Precision grasp applies when manipulating small objects such as holding a thread to pass through the eye of a needle. For robotic application however,

[15] notes that detailed classification for grasping is not necessary. The more important consideration is whether there is contact or no contact between the hand and the grasp taxonomy containing 16 hierarchical structures based on the example of the grasping motion of workers in a machine factory are available. Based on this system, hand functions are broadly classified into contact or non-contact with the object. Figure 7 shows the classification of hand functions.

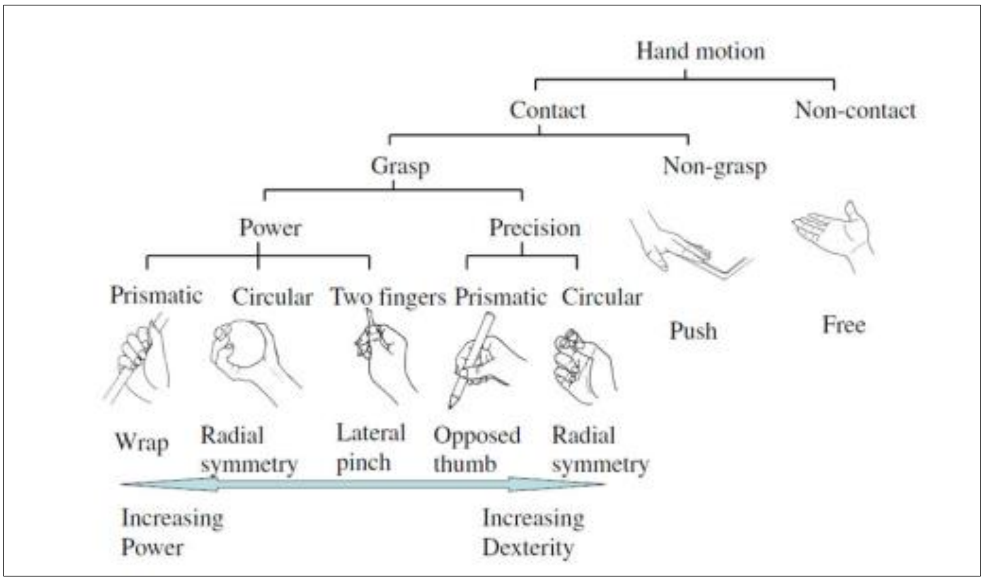


Figure 7 Classification of Hand Functions [15]

In the grasp range, dexterity requirements increase from left to right, while power requirements increase from right to left. The human hand has about thirty (30) degrees of freedom. It is difficult to reproduce its strength, flexibility and sensitivity. The Shadow hand – an advanced robotic hand is driven by 40 air muscles. Dexterous manipulation requires hand-arm coordination of two hands and the vision system. Due to the high number of joints involved, controlling grasping and manipulation is challenging. Figure 8(a), 8(b), 8(c) and 8(d) show the different movements associated with different elements of the human hand namely: forearm, wrist, fingers and thumb. Actuation of these elements are facilitated by muscles as shown in Figure 9 (a) and 9(b) respectively.[16].

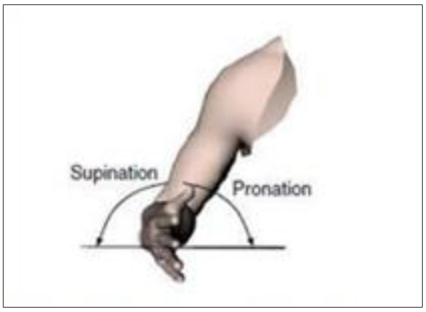


Figure 8(a) Supination and Pronation

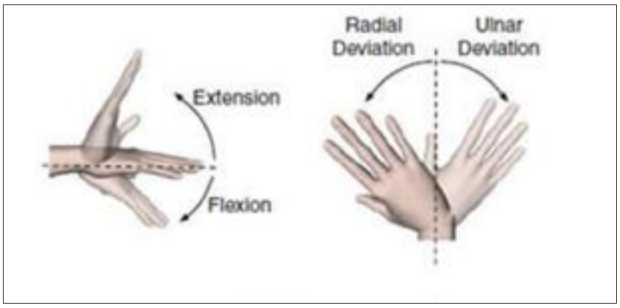


Figure 8(b) Radial and Ulnar Deviation

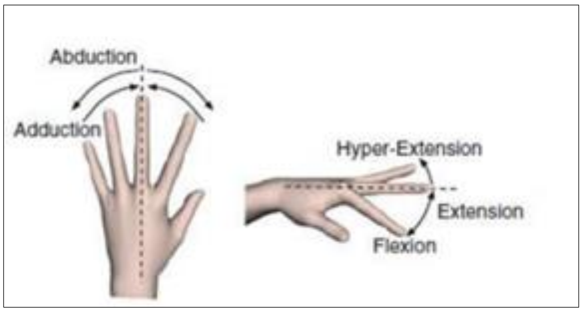


Figure 8(c) Adduction and Abduction with Hyper-Extension

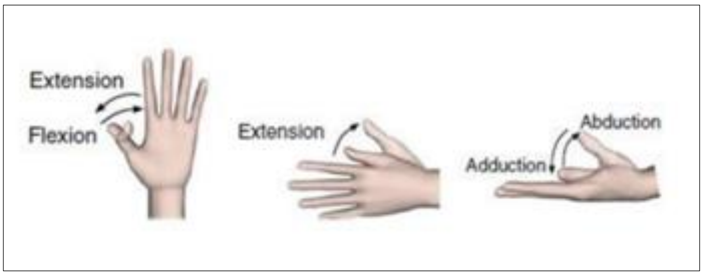


Figure 8(d) Adduction and Abduction without Hyper-Extension

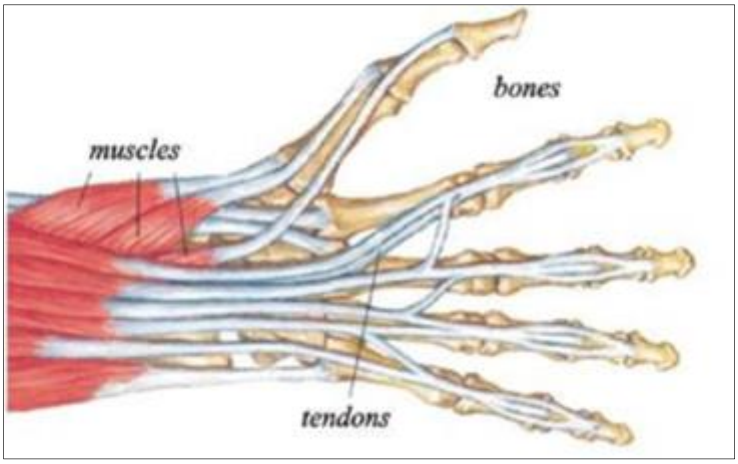


Figure 9 (a) Biological Actuation of the Human Hand [16]

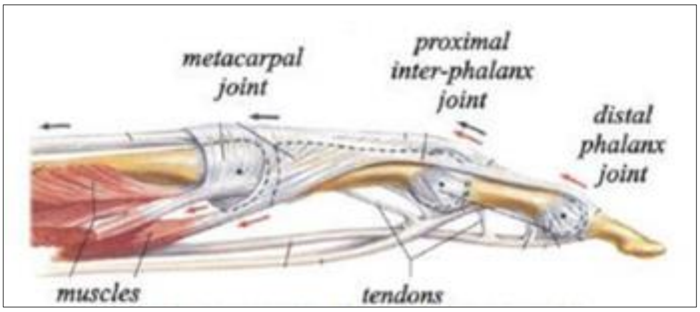


Figure 9(b) Biological Actuation of the Finger [16]

Three examples for manipulation-oriented humanoid robots are the Robonaut – using the space tools designed for human use. Although the performance of such robots are impressive, they cannot grasp and manipulate unknown objects – due to deficits in the perception of grasping affordances. Also, the interpretation of the touch and force sensors integrated in the hands must be improved so as to allow for blind adjustments of hand grip in the way humans are capable of doing One of the first instances of a mechanical device designed to carry out physical tasks occurred in Egypt about 3000BC. The Egyptian water clocks used human figurines to strike the hour bells. In 400BC, Archytus of Taremtum - the man who invented the pulley and screw, invented a wooden pigeon that could fly. Helenic Egypt also witnessed hydraulically operated statues that could speak, gesture and prophecy. In the first century AD, Petronius Arbiter made a doll that could move like a human. In 1557, Giovanni Torriani created a wooden robot that could fetch the Emperor's daily bread from the store.in the 1700s, several ingenious, yet impractical automated machines (robots) were created. Such innovations extended right into the 19th century including the talking doll made by Edison and a steam-powered robot made by the Canadians.

According to the Robot Institute of America, a robot may be defined as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through various programmed motions for the performance of a variety of task". The first use of the word "robot" occurred in a play (in 1921) about mechanical men that were built to work on factory assembly lines and that rebel against their human masters. Robot in Czech means slave. The story occurred in a playwright by Karl Capek titled "Rossum's Universal Robots". The mechanical servant in the play had a humanoid appearance. The first humanoid robot to appear in the movies was Maria in the film "Metropolis. In the 1939 and 1940 World's Fairs, Westinghouse Electric Corporation exhibited the tall motor man, named Elektro. It was a humanoid in appearance; could drive on wheels in the feet, play recorded speech, smoke cigarettes, blow up balloons, and move its head and arms. The Elektro was controlled by 48 electrical relays and could respond to voice commands. Isaac Asimov first used the word – "robotics" – in 1942 written in his short story: "Runabout". Asimov presented robots as helpful servants of man and viewed them as "a better, cleaner race". In 1952, Ozamu Tezuka created the first and one of the world's most popular Japanese sci-fi robots, named Astroboy. Wabot-1 was the first full-scale anthropomorphic robot: able to walk on two legs. It could also communicate with a person in Japanese and was able to grip and transport objects with the aid of its touch-sensitive hands. The group of Ichiro Kato also developed Wabot-2 – a robot that could read music and play an electronic organ. Wabot-2 was equipped with a hierarchical system of 80 microprocessors. Its arms and legs had 50 degrees of freedom. It was demonstrated at the Expo in 1985 in Tsukuba, Japan.

The earliest robots as we now know, were created in the early 1950s by George Devol. He invented and patented a reprogrammable manipulator called "Ultimate". In 1960s, businessman and Engineer Joseph Engleberger acquired Devol's robot patent and was able to modify it into an industrial robot and formed a company called Unimation to produce and market the robots. Engleberger is known in the industry as "the Father of Robotics" – due to his efforts and successes in the development of robotics technology.

In 1996, P2 was unveiled by Honda to the public – in process to fulfil their goal that robots "should coexist and cooperate with human beings, by doing what humans cannot do, and by cultivating a new dimension in mobility to ultimately benefit society." The P2 was the first self-contained full- body humanoid. It was able to walk on flat floors and also climb stairs. The next year, P3 was unveiled and a more advanced humanoid design in 2002; named Asimo. The Sony Dream Robot named Qrio was unveiled by Sony in the year 2000, could recognize faces, express emotion through speech and body language, and could walk on flat as well as on irregular surfaces.

According to [17], the Robotics Institute of America (RIA), Association Francaise de Robotique (AFR) and the Japanese Industrial Robot Association classify robots as follows:

- Class 1: Manual handling devices: a device with multiple degrees of freedom and actuated by an operator.
- Class 2: Fixed sequence robot: a device that performs the successive stages of a task based on a pre-determined and fixed program.
- Class 3: Variable sequence robot: a device that performs the successive stages of a task according to a predetermined but programmable method.
- Class 4: Playback robot: a robot in which a human operator carries out the task manually by leading the robot, which records the motions for later playback. The robot repeats the same motions according to the recorded information.
- Class 5: Numerical control robot: the operator provides the robot with a motion program rather than teaching it the task manually.
- Class 6: intelligent robot: a robot that has the ability to understand its environment and with the ability to successfully complete a task despite operational dynamics.

Other classifications of robots are based on criteria of geometry, workspace, actuation, control and application.

Robots with anthropomorphic arms and hands can be used to generate gestures. At least four joints per arm are needed. KAIST developed an upper-body robot named Joy in Korea, capable of generating a variety of gestures. Humanoids generate symbolic gestures, such as greeting and waving, batonic gestures – which emphasize accompanying speech, and pointing gestures – which indicate a direction or reference an object. The size of objects can also be indicated with arms and hanrthermore, robots with articulated fingers such as Hubo can even be used to communicate with sign language.

More advanced forms of humanoids are andriods and gynoids, which aim for a photorealistic human-like appearance. Silicone skin is used on such robots, they have human-like hair and are dressed as humans. Although the synthesis-part of multimodal interaction works reasonably well, the insufficient perception performance of the computer vision and audition systems and the lack of true meaning in the dialogue systems so far prevent humanoid robots from engaging in truly intuitive multimodal interactions with humans.

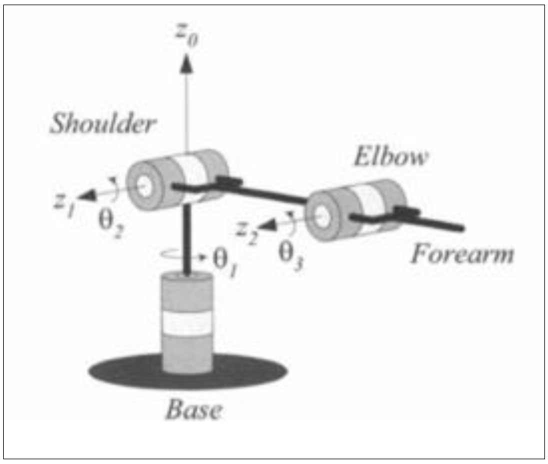


Figure 10 Revolute joint in a 3R manipulator robot [17]

Humanoid robots are used mostly in technology demonstration, space missions, manufacturing, household aid, and robot competitions. Famous humanoid bots like the Asimo or the Partner Robots do not accomplish any useful work, rather, they are used to demonstrate their capabilities such as walking, running, climbing stairs, playing musical instruments or conducting orchestras on stage and during exhibitions. Space robots like the NASA Robonaut use a humanoid torso mounted on a wheel base. In manufacturing, the Motoman-SDA10 robot for instance, has two arms with 7 degrees of freedom on a torso that has an additional rotational joint. It is capable of holding a part with one arm while using a tool with the other arm. It can also transfer a component from one arm to another without setting it down. Humanoid robotic technology is not used very much in household applications; however, some models have been developed to aid in cooking. Robot competitions for humanoid robots include soccer bots and tennis playing bots. These robots are fully autonomous and play together as a team. They can get themselves up and continue playing if they fall. Another popular humanoid robot competition is Robo-One – where tele operated robots engage in martial arts.

The motion of robots is facilitated by a combination of links connected by joints to form a kinematic chain. The basic form of industrial robot called the manipulator has a base, shoulder, elbow, forearm, wrist and gripper. The joints in robots are typically revolute (rotary) or prismatic (linear). Figure 10 shows a revolute joint (R) – like a hinge that allows relative rotational motion between two links.

On the other hand, a prismatic joint (P) allows translational motion between two links as shown in Figure

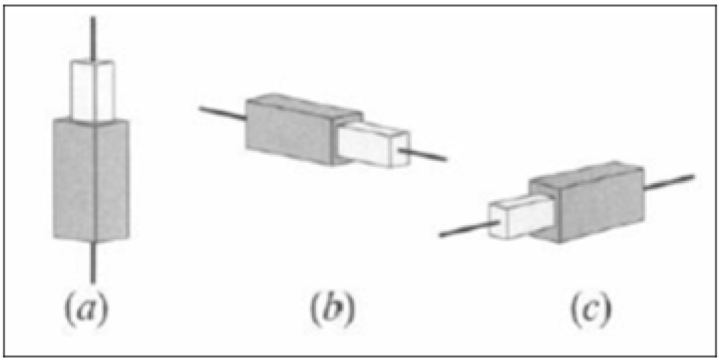


Figure 11 Prismatic Joints [17]

Revolute and Prismatic joints are the most common joints that are utilized in serial robotic manipulators. Other joints types (ie cylindrical, screw, spherical and planar) are merely implementations to advanced robotic hands, the simulation of the skin and neuromuscular control. Parameters for modelling and scaling the hand are indicated as HL is the hand length while HB is the hand breadth.

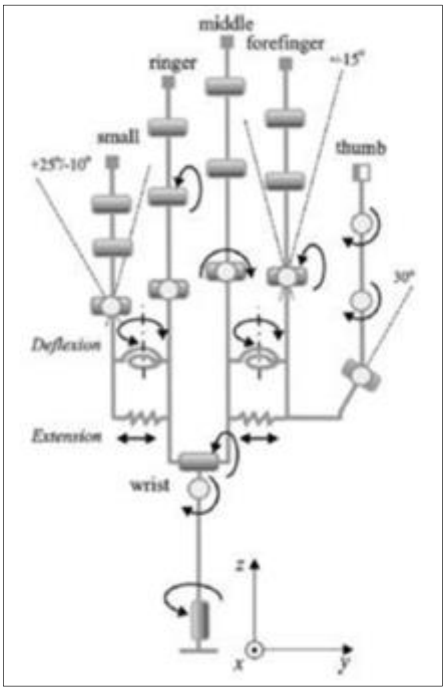


Figure 12 Front View of the Kinematic Scheme of the ‘Pupin Hand’[16]

[2]worked on the design method for an anthropomorphic hand capable of gesturing and grasping. They indicated that there are no numerical methods for the thumb placement: existing models usually apply the result of successive parameter adjustments. In the study, a surgery test and workspace analysis of the whole hand are used to find the best thumb position and orientation according to the hand kinematics and structure. The result was validated through simulation – where the hand is assessed and result showed the hand looks well balanced and meets the constraints and set objectives for the study.

[19]presented a paper on the development of anthropomorphic robot hand of modular structure. Their hand dubbed "Pupin hand" had 23 degrees of freedom. The model of rigid body dynamics of the Pupin hand was defined by corresponding differential equations; with assumption that no inertial coupling existed between the motors and the joints, being that the motors are dislocated into the forearm according to the mechanical design. Futaba RC motors were used for the actuation of the hand model.Figures 12 and 13 show the front and end views of the schematic scheme of the' pupin hand'.25

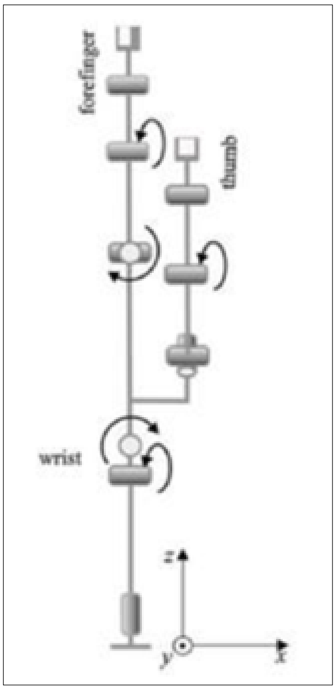


Figure 13 End View of the Kinematic Scheme of the 'Pupin Hand'[16]

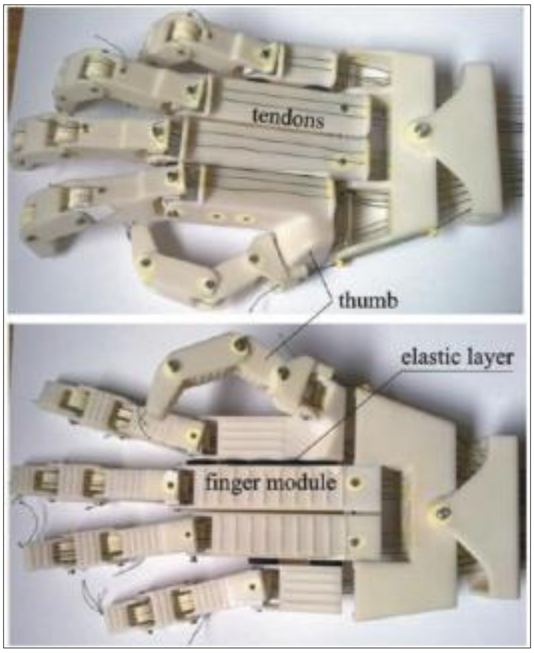


Figure 14 The 3D-Printed "Pupin Hand" [16]

Figure 14 shows the 3D –printed of pupin hand'

Buchholz and Armstrong (1992), developed a kinematic model of the human hand to evaluate its prehensile capabilities. Their study involved the simulation and prediction of prehensile capabilities of the human hand. The model was based on an algorithm that determines contact between two ellipsoids, which are used to approximate the geometry of the cutaneous surface of the hand segments. Algorithms for two grip types were included: transverse volar grasp (which has the thumb abducted for added power) and a diagonal volar grasp (which has the thumb adducted for an element of precision). To validate the predictive capabilities of the model, joint angles were measured on six subjects grasping circular cylinders of various diameters and these measured joint angles were compared with angles predicted by the model. Sensitivity of the model to the various input parameters are computed as well. It was discovered that on an average, the model predicted joint flexion angles that were 5.3% i.e. 2.8º ±12.2 º larger than the measured angles. Also, the MCP and PIP joints were observed to have good agreements, but the results for DIP were more variable due to its dependence on the predictions for the proximal joints.

Productivity in the manufacturing industry has been revolutionized by the introduction of robots. They can be programmed to carry out several manufacturing tasks such as: pick and place, welding, fitting, painting. The reason they have been widely adopted in manufacturing industries is because they are more accurate, precise, and faster than humans[17]. They produce required results consistently and continuously for several hours without rest. Assembly robots are programed to put parts together using screws, pins or dispense adhesives. Figure 16 shows an assembly robot in operation.

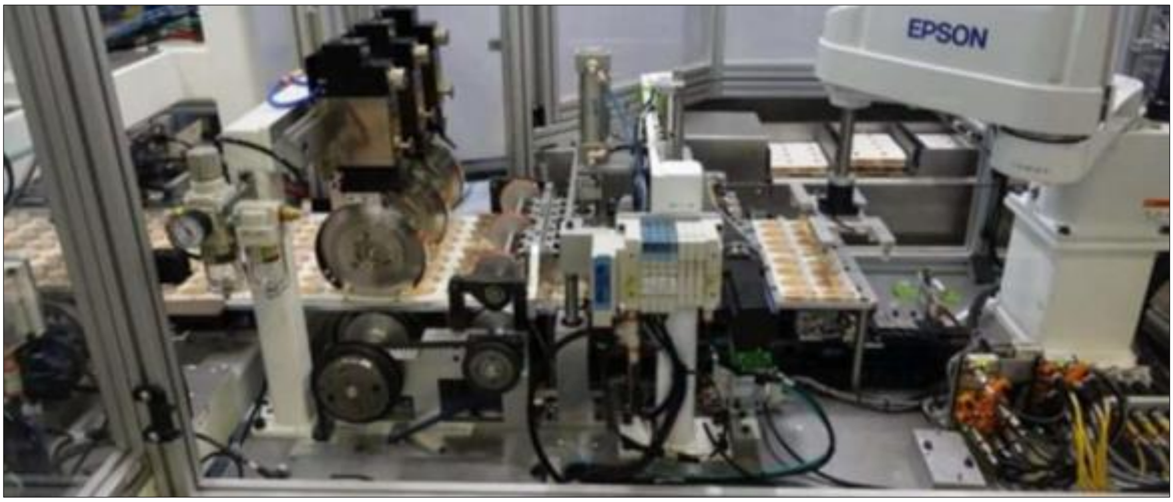


Figure 15 An Assembly Robot in Operation [18]

They can carry out operations involving delicate, miniaturized or intricate units. They utilize computerized vision system, motion and force feedback sensors to carry out their tasks to high standards. Industrial robots carry out hazardous tasks or delicate ones. Figure 16 shows a robot that can be used in welding operation. Since they do not emit contaminant gases, they are used in the electronics, pharmaceutical and medical device industries in material handling and products assembly [19].

Human beings have two hands – thereby making it possible to manipulate certain objects that cannot be handled with one hand only. For the same reason, humanoid robots have two hands.

Certain forms of assembling require the use of both hands to carry out tasks. Collaborative robots – also known as “cobots’, are designed to work synchronously to handle irregular objects, assemble complex systems or carry objects of large scale. Collaboration involving multiple robots results in greater work efficiency with reduced impact of partial malfunctioning. In comparison with single robot operation, multiple robots in collaboration can carry out material transport, cutting, or assembly in a loop operation. However, the kinematics of robots operated in collaboration is more complex than that of a single robot[20].

The hand is a vital part of the human body. If lost through accident or by any other means, its effect on the individual could be devastating. Imagine a person who is the bread winner of a household rendered unable to work to earn a living; the effect could be colossal. Unfortunately, studies show that men are more likely to lose their hand than women [21]. Historically, a hand amputee only had an option of using a hook prosthesis; this had limited function and there was a significant level of social stigma associated with it. In the modern society however, advancements in medical engineering has made it possible to have bionic hands that closely resemble the human hand in every way – in appearance and function [21],[22]. Figure 20 shows an example of a modern prosthetic hand which demonstrates how similar modern prosthetic hands are similar in function and appearance to the human hand. Modern bionic hands are lightweight and are driven by battery embedded in it. Most limb users can use their hand for at least 8 hours per day, before having to recharge. The actuators that control the hand are driven by electrical ("motor") signals in the human body [21]. Figures 17 and 18 show the intelligent design of the bebionic Hand.

Figure 16 Welding Robot [19]

Figure 17 iLimb Hand – A Modern Prosthetic Hand [21]

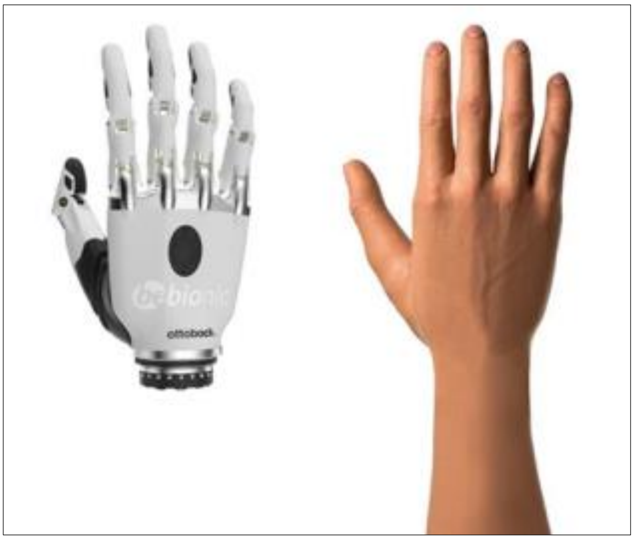


Figure 20 Intelligent Design of the Bebionic Hand [22]

The design of hand kinematics is a very important aspect of the robotic hand design process. It involves assessment of the objectives of the design; consequently, the requirements of the thumb, the fingers and the palm. The kinematics of robot hand can be evaluated based on empirical criteria or analytical criteria.

The human hand is assessed based on empirical results. It involves the use of data gloves – a glove worn on the hand and used for hand motion capture. This method is expensive. [23] notes two methods implemented in carrying out the kinematic analysis: cadaver analysis resulting in a five-link kinematics hand model and the use of Magnetic Resonance Imagery (MRI) data acquisition and analysis. In the later method, segmentation algorithms are implemented to extract information on bones motion; resulting in the hand kinematics.

The human hand kinematics can be assessed on based on mathematical criteria or with hand and grasping simulation tools [23]. The mathematical criteria involve manipulability ellipsoids, dexterous workspace or grasp stability[On the other hand, simulation tools can be used to evaluate hand grasping. Such tool includes "GraspIt"- a complete simulation environment that is used for the simulation of facilitates simulation of "hands-in-contact situations" [22].

There are two main methods of evaluating the kinematics of a robot hand: mathematical criteria (using manipulability ellipsoids, dexterous workspace or grasp stability) and simulation tools on hand and grasping Furthermore, the grasping test can be done with cardboard models or "GraspIt"

According to [23] due to variations in human hands, attempt will not be made to replicate human hand operation in an exact form; rather, the hand function – derived from the human hand kinematics – will be the main criteria and basis of performance evaluation.

[23] notes that, based on decades of hand surgery and day to day handling and manipulation of objects with the hand, it seems more effective to use physical assessment as basis for evaluation than using mathematical abstractions. Therefore, the human hand will be studied; then a model will be produced which will be used to assess the kinematics using a series of tests. Tests on human hand kinematics can be categorized as: hand surgery-based tests, grasping tests and aesthetic tests.

2. Material and methods

Developing the robotic hands is not intended to replicate actual human hand working principle, but to mimic the kinematics for effective grasping and manipulation performance. This is due to the fact that packaging constraints hinder the number of actuators that can be used and the robotic mechanism requires the use of technology that is not a biological equivalent. Essential features that are found on the human in the development of the robotic hand include: lengths of the fingers, applied couplings and degrees of freedom at the joints, the thumb position and the hand kinematics.

Typical and dimensions of human hand is shown in Figure 21 Figure 22 shows a computer-aided 3D model of the human hand derived from the standard range of dimensions of the human hand.. These dimensions are based on actual measurement of a human hand. The model hand has 24 degrees of freedom – generated from 19 links – as it is in a typical of a human hand.

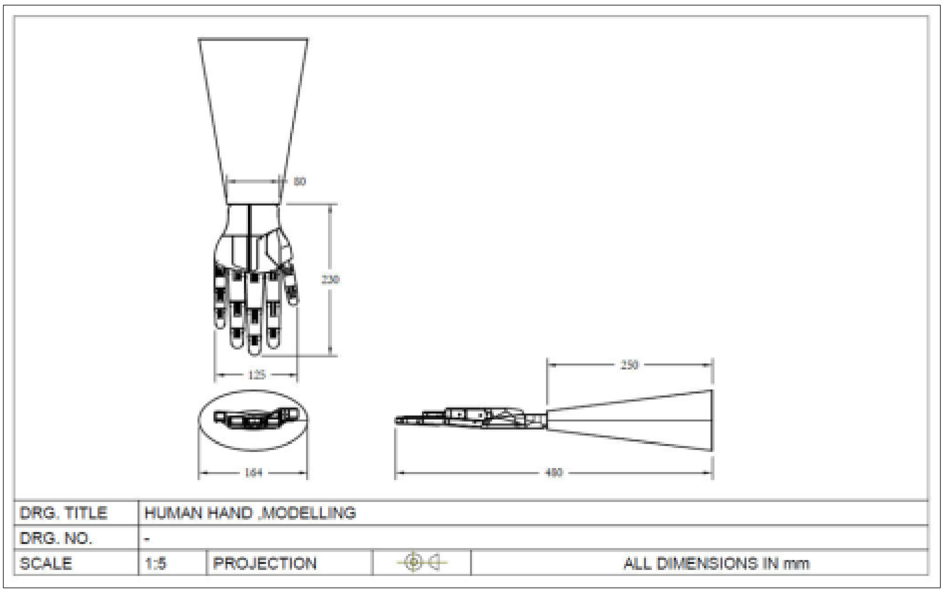


Figure 21 Dimensions of the Human Hand

Figure 22 3D Model of the Human Hand 34

The robot hand can be used to grip objects of different shapes and sizes. The kinematics of the human hand is best analysed based on direct kinematics and inverse kinematics. The forward kinematics is applied to determine the position and orientation of the fingertip. Figure 23 shows the kinematic configuration of the human hand model designed with 23 degrees of freedom.

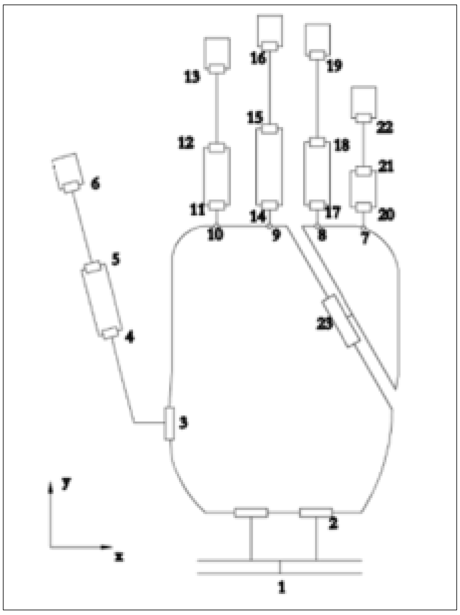


Figure 23 Kinematic Analysis of the Human Hand

Homogeneous transformation matrices are used to derive the kinematic model of the hand. Since the hand movements are generally rotational and translational, matrices are used to describe the movement relative to the x, y, z coordinate system. The linear motion is described by the matrix

Based on these matrices, the final position of a particular finger can be determined. For robust computation of the finger positions and movements, MATLAB software can be used. The SynGrasp MATLAB toolbox can be used in the analysis. With SynGrasp, the hand is modelled and contacts defined. Using the built-in analysis tools, the effectiveness of the hand model in performing grasping tasks to be assessed.

Antagonistically driven joints have actuators connected to either sides of the joint. Tensioning in this case is provided by the drive train itself. Figure 24 shows the antagonistic actuation method which will be implemented in this design.

The hand can be developed and actuated by 12 electric motors which can be driven by the Arduino controller.

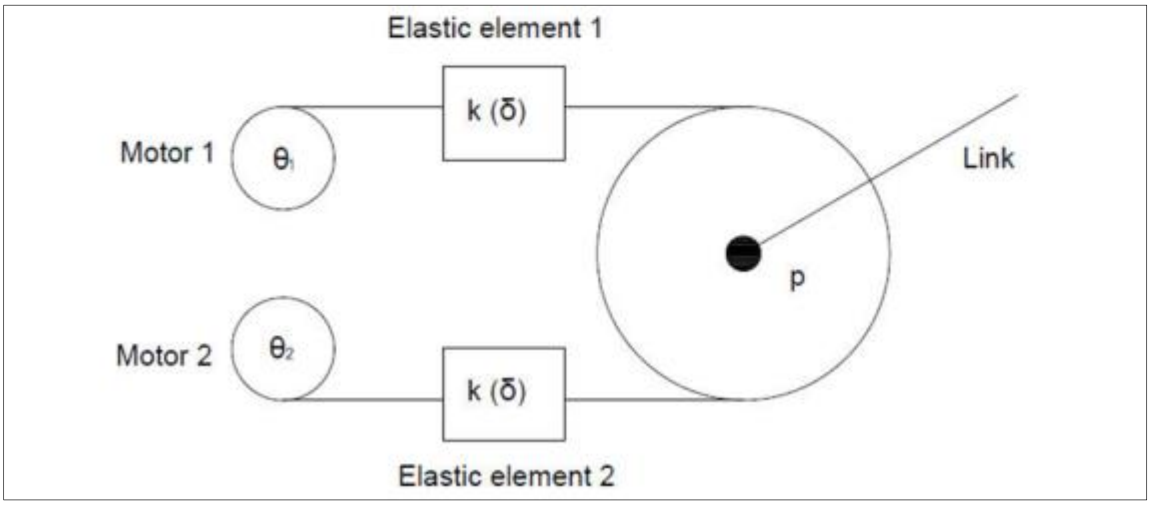


Figure 24 The Joints Antagonistic Control Scheme

In Figure 24, it can be seen that for each link, two servo motors are used to provide requisite operating force. $\theta 1$ and $\theta 2$ are the angular positions of the first and second motors respectively. k (δ) represents the stiffness characteristics. P indicates the link position.

3. Discussion

Developments in robotics design and control is based on its kinematics capabilities. The human hand remains the practical model for study, copy, mimic and adaptation to kinematic kinematics analysis and applications. Human arm kinematics is based on the geometry or configuration of the arm, joint types, number of joints and powering. Powering here means the energy applied to the joints. Beginning from the fingers, a normal human has five fingers with three bones in each finger, strategically placed: proximal, middle and digital phalanges. These fingers are of different lengths capable of extending inwards and outwards-adduction and abduction. Each finger is also capable of flexion- projecting down and hyper-extension-upward lift. These are capabilities to extend, hold, grasps or pick objects as desired by the designer. At the proximal phalanges, the fingers are linked to metacarpals and finally to Ulna and radius joints. All the joints have manipulative capabilities. The CMC, PIP and DIP are hinge joints –one degree freedom permitting movement towards and away from the palm. Every finger is designed to ensure effective hands functions limited to human arm. With the help of the forearm, wrist, fingers and thumbs, supination and pronation (rotations) are possible [16] Dexterous manipulations are also possible in extension, flexion Ulnar and radial deviations. These are used when more complex or power demanding tasks are necessary.

Hand motion is basically as contact and no contact. The hand contact has more meaning in real life and kinematics and robotics applications. In grasping, power may be given upper consideration with respect to precision or precision with respect to power [14]. They are oppositely directed. Therefore in the design of robots this should be among the design definitions

4. Conclusion

Human hand kinematics is vital to improvement in robotics manipulations. Identification of the limitations of joints of the fingers can probe into introducing joints that will overcome and facilitate more degrees of freedom for the robotic manipulations and control. It is possible to define new task or functions for robots. Future research should be on defining the new task, that if done will improve the capabilities of robots in kinematics applications for various functions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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