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Analysis of a Biomimetic Anthropomorphic Robotic Hand/Prosthetic

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Abstract: *The need for a prosthetic that imitates its human counterpart in design arises from the need to have it imitate the limb in its function. A prosthetic that is designed with a close resemblance to the actual limb, could be manipulated very intuitively, and thus, the requirement of special therapy or training would be minimum.*

Prosthetics, as they are being designed currently, fall short of this, because the various joints in the limb (the human hand) are overly simplified, which hinders the prosthesis' functionality.

Thus, to design an anthropomorphic prosthetic hand, it is important to understand the structure and mechanics of the human hand from an engineering stand- point. To do this, it is first necessary to study the various functions of the human hand and how its structure plays an important role in them.

This analysis aims at understanding the natural methods by which we manipulate and grasp daily objects, and how this knowledge will play a pivotal role in adapting the human hand structure in a prosthetic hand. This research paper addresses the necessity and aptness of such a hand prosthetic.

The paper aspires to investigate the various intricacies of such a design. It attempts to follow the various steps taken, from the analysis and classification of various grasp methods to their kinematic modelling, and ultimately, its incorporation in a biomimetic anthropomorphic prosthetic.

Keywords- *DOF-Degrees of freedom, MCP joint-Metacarpophalangeal joint, PIP joint- Proximal Interphalangeal joint, DIP joint-Distal Interphalangeal joint, CMC joint Carpometacarpal joint*

I. INTRODUCTION

A. Basic Terminology

Biomimetic refers to the study of natural elements, systems and attempting to incorporate the studied principles into solution to a complex problem. It intends to take advantage of the fact that nature has had millennia to develop its systems, therefore solutions inspired by nature would be better suited to deal with a real-world situation. Anthropomorphism refers to attribution of human characteristics to an object.

In that sense, an anthropomorphic robot would have physical characteristics and kinematic principles modeled after a human or a suitable counterpart. Originated from Ancient Greek, Prosthetic (addition/attachment), is an artificial device that supplants a missing body part, which might be lost through trauma, disease, or some congenital conditions. To restore the normal functions of the missing body part, Prosthetics are required

B. Scope of the Research Paper

The research paper critically analyses the anatomy of the human hand and the role it plays in its function. It is directed towards imitating the anatomy and operation of the human hand. While attempts have been made to imitate it exactly, certain adaptations have to be made in order to make the design feasible and account for some fundamental differences viz. the material used, the method of actuation, the methods of control, compliance of joints etc.

After consideration of all the differences and the adaptations made, it is necessary to investigate how well the prosthetic measures up against the actual human hand. This is done by subjecting the hand and the prosthetic to certain load conditions. They are then subjected to random amounts of flexion and relaxation. Second and third order mathematical models are considered while trying to model the motion. The fit of each mathematical model to the hand and the prosthetic is considered to establish the correlation between their function. A modified second order equation shows the best fit to the recorded data, and also establishes a close similarity between the hand and the prosthetic.

II. LITERATURE REVIEW

A. Human Grasp Choice and Robotic Grasp analysis

The paper goes about with a review of studies of human grasping, particularly, the development of a grasp taxonomy and a system for human grasp choice prediction. The object geometry and task requirements (as well as hand capabilities and tactile sensing) combine to dictate grasp choice analyzed by the study. Analytic models of grasping and manipulation with robotic hands are considered. Different approaches for robotic grasp and manipulation planning are suggested which provide insights to why people grasp and manipulate objects and issues such as object representation and hand design are studied.

B. Design And Analysis Of Artificial Finger Joint For Anthropomorphic Robotic Hands

It is necessary to develop artificial joints that are anatomically correct while sharing in order to further understand what physiological characteristics. Hence we address the problem of designing a 2 DOF index finger metatarsophalangeal (MCP) joint. The artificial MCP joint is composed of a ball joint, crocheted ligaments, and a silicon rubber sleeve which as a whole provides the functions required of a human finger joint. Our new joint is a good estimate for an index finger's MCP joint and parameter approximations of stiffness and damping are found to be similar in artificial joint.

C. Synthesis of a Biomimetic System

While adapting the natural elements into solutions, it is important to understand which features and characteristics to imitate exactly, which can be simplified and which can be completely substituted. This is because while functionality is important, the feasibility of the solution needs to be taken into consideration too.

The overall scope of the solution, its operating parameters, available manufacturing capabilities and total cost of implementation need to be taken into account.

Even though the knowledge of human hand anatomy and the mechanics of its operation have been understood for a long time, the technology to synthesize a solution that would best incorporate this knowledge is very recent, as will be seen in the methodology adapted. Also, since the scope of this paper was to synthesize a prosthetic that imitated the human hand in every way, all attempts were directed towards directly imitating the hand. However, in certain cases, the solution does go as far as simplifying certain features. But, in no case whatsoever, has there been a complete substitution of operational features.

III. METHODOLOGY

There is a need to understand the actual taxonomy of the human hand and how it enables us to manipulate a wide variety of objects. First, we will broadly classify the natural grasp methods based on what objective it is supposed to achieve as:

- 1) Power grasp
- 2) Precision grasp

A. Grasp Taxonomy

There are two main approaches to understanding human grasp. One involves the principles of bio mimicry, in that it hopes to understand how humans perform so well. The other approach involves study of the human hand from a kinematic point of view. Each approach, by itself, is not sufficient to satisfactorily model the human hand. This is because limitation in technology and computational power leads to simplification of mechanisms in case of the biomimetic approach, and of equations in case of analytical approach.

Fortunately, these two approaches complement each other. Study of natural systems helps to assure that the analytic models are not overlooking important effects. Analytic work helps to explain why people do what they do which provides insight for design and control of dexterous robot hands. For instance, a sphere provides a spherical grip and on the other hand a cylinder provides a wrap grip. But, when people use objects in routine tasks, the choice of grasp is less driven by the shape and size of objects than by the tasks they want to pursue. If the object is a little more or less cylindrical, then a wrap is chosen. Since many objects, including the handles of most tools, have cylindrical shapes, the power wrap represents a large family of grips. On the contrary, the different precision grasps appear to be driven by part geometry, hence the decision to use one precision grasp instead of other may actually be task related because many objects have several gripping surfaces with different shapes.

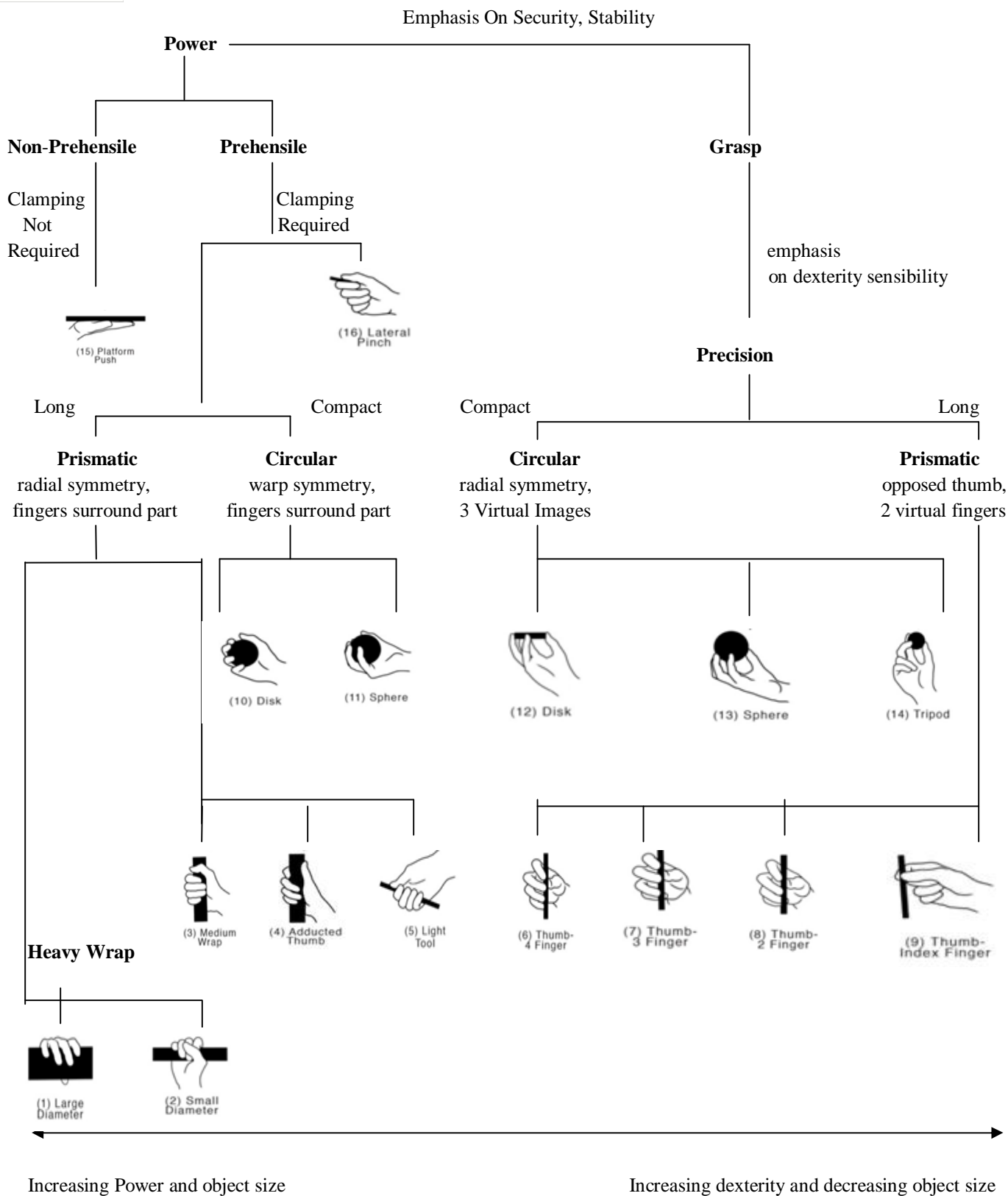


Fig1: Grasp Taxonomy

B. Structure of Human hand

Next, we will classify based on the shape of the object to be handled. This will enable us to understand the mechanics of the hand which are crucial in its operation.

We will study the shapes of the bones/joints that allow the hand its various degrees of freedom. The kinematic function of the shape of the bones will be understood, which will help in appropriate adaption of their structure in the prosthetic.

The primary objective is to understand the function of the human hand from a kinematic standpoint and its stiffness adaptive property of a joint. Also, study and enlist the degrees of freedom of various joints, and explain their importance in the dexterity of the human hand. The structure of human hand and related terminology is as follows:

- 1) **MCP Joint:** Metatarsophalangeal joint. It is the joint between the metacarpal bone and proximal phalanges.
- 2) **PIP Joint:** Proximal Interphalangeal joint, between the phalangeal bones, nearest to the knuckle.
- 3) **DIP Joint:** Distal Interphalangeal joint, between the phalangeal bones, near the end of the finger.
- 4) **CMC Joint:** Carpometacarpal joint, between the thumb and the palm.

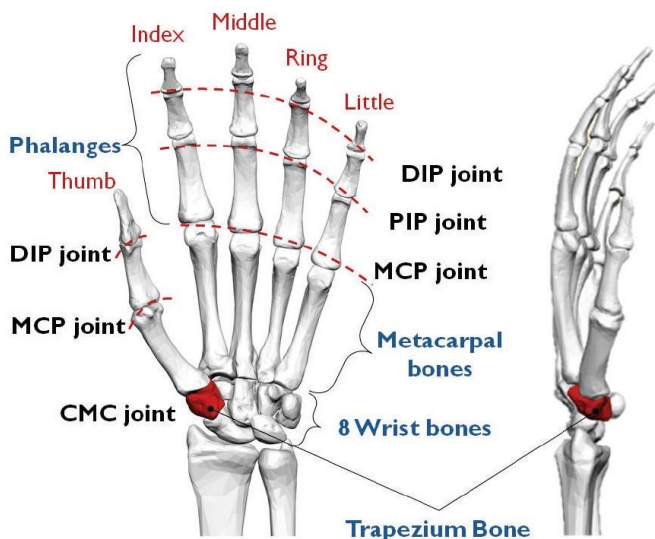


Fig2: Structure of Human hand

Degrees of freedom of human hand

Finger				
Joint	DIP	PIP	MCP	Total
DOF	1	1	2	4
Thumb				
Joint	DIP	MCP	CMC	Total
DOF	1	1	3	5

$$\text{Total DOFs} = (4 \text{ Fingers} \times 4) + 5 = 21$$

C. Dynamics of Human hand

To mimic the functional characteristics of the natural human joint in its entirety, it is essential to emulate the dynamic characteristics of the joint. The crocheted ligament sleeve, woven in a hyperbolic profile from an artificial fiber that is strong, stiff and slides smoothly over the joint material, provides stiffness to the joint. A silicon sleeve fit over the joint is used to replicate the elastic property of the natural finger joint. It gives the joint a certain springy quality and compliance.

Various properties such as density of the weave or fiber thickness in case of ligament sleeve and elasticity of silicon rubber sleeve are designed to closely mimic the actual human joint. The analysis of human grasp tendencies reveals that task plays an important role in determining the type of grasp selected, in conjunction with shape of the object and the precision/power requirement of the task. Analysis of the human hand explores the various kinematic features of the hand. A total of 21 active DOFs are present in the human hand that make a wide variety of manipulation tasks possible.

The dynamics of the human hand was studied, which reveals that but stiffness and elasticity are necessary for the joint to function properly. This stiffness and elasticity properties were incorporated into the joint using a joint ligament woven from an artificial fiber for the stiffness and a silicon rubber sleeve for the elasticity. Elasticity in the joint allows for compliance, which further allows the hand to be under-actuated. This means that all the available DOFs are not actively controlled by the drive arrangement. The compliance of the joint means that the fingers rest in an optimum position for the given grasping task.

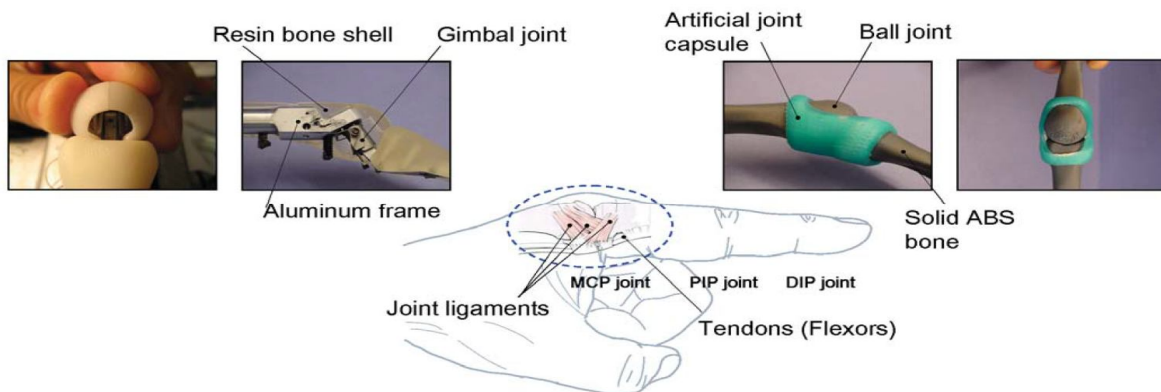


Fig3: Dynamics of Human hand

D. Joint Stiffness, Compliance and Elasticity

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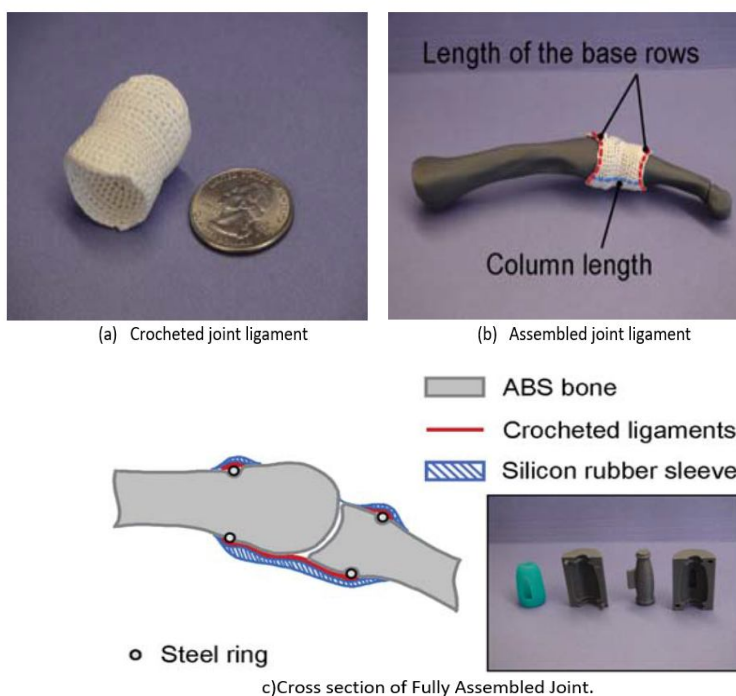


Fig4: Joint Stiffness, Compliance and Elasticity

IV. CONCLUSIONS

The design and modeling of an artificial finger joint that has the potential to become a close replica of the MCP joint in the human hand has been done. The artificial joint makes use of three main components: a ball joint with true to life bone topology, crocheted ligaments used to realize the right range of motion, and a rubber sleeve of silicon which provides the passive accordance for the artificial joint. For our system identification, two key design parameters were investigated to optimize the models derived for the MCP joint of the index finger. The model is in good agreement with the data collected from both the MCP joint of the artificial and human index fingers. We expect to apply a similar design to both the PIP and DIP joints and have already designed and fabricated an extensor tendon hood so that each joint of the artificial finger will eventually be actuated by a series of extensors and flexors in the same way as a human hand.

The design of this finger joint has been incorporated into designing the prosthetic. Lack of economical engineering knowledge of the human hand and the limitations caused by conventional mechanical joints are the significant constraints that limits the development of anthropomorphic prosthetic during the process. And then we construed the comprehensive ways to imitate important biomechanical benefits of the human hand with the processes that robot cists can easily understand. To summarize, our proposed robotic hand design has better repeatability in finger movements and thus can be teleported to grasp and manipulate a wide variety of daily routine objects under current design and was experimentally demonstrated

In future work, we are planning to incorporate biomimetic wrist design and already- developed fingertip sensors into our robotic hand so that we can further improve its telemanipulation performance. Furthermore, due to the latent analogy between our robotic hand and its human counterpart, it can further explore its potential to serve as a bio- fabricated device in the emerging fields of neuron-prosthetics and limb regeneration.

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