The development of interfaces that link the human musculoskeletal system with robotic devices has been a major area of research within rehabilitation robotics. Most of the research is focused on restoration of motor and sensory functions to those with degenerative diseases, injury or amputees. The basic goal is to enhance capability for independent living and vocational productivity by restoring the physical functionality through use of prosthesis. One of the key focus has been upper limb prostheses for people with manipulative disabilities. Bio-signals driven prosthetic hands have been found to be suitable; wherein control is through conveying human’s intention to the prosthesis. There are two possible bio-signal based schemes covering the approaches for conveying human’s intention to the prosthesis.

- Electroencephalogram (EEG) based approaches
- Electromyogram (EMG) based approaches

EEG based approaches are implemented through an interface between the brain and the prosthetic hand to be controlled. The activity of the brain is recognized based on the EEG signals (5). On successful recognition of brain’s activity; the prosthesis emulate the amputee’s intention through the interface. Due to localization of brain activities and multidimensional aspect of the EEG signals, analysis and classification of EEG signals are challenging. Moreover, the appropriate number of channels as well as their specific location on the scalp requires identification. Failing to do so results in degradation of system performance. In many cases, there is no clear agreement about the number and location of necessary channels to collect EEG signals. Using a small
number of channels may cause loss of important information. Conversely, including more channels for data collection provides redundant information, which could degrade the system performance.

In EMG based approaches, an indirect interface between the brain and the prosthetic hand to be controlled is established based on the muscles’ activity through EMG signals (6). EMG is the electrical manifestation of the neuromuscular activities and is known to reflect the voluntary intention of the central nervous system (7). Interpreting the content of the EMG implies the interpretation of the brain’s activity to contract a muscle or a group of muscles. EMG based approaches for prosthetic hand control is a targeted reinnervation as it collects information from specific muscles; responsible for specific functions.

1.1 EMG Controlled Prosthesis

The concept of EMG control has emerged essentially as a control paradigm for prosthetic hands in which the EMG signals are acquired from the muscles remnant in the amputee’s stump. This still have normal innervations (8) and thus subjected to voluntary control. It allows amputees intuitively to use the same mental process to effectively control their prosthesis. A schematic of EMG controlled prosthetic hand is shown in Figure 1.1.

![Figure 1.1: Schematic of EMG controlled Prosthetic Hand](image-url)
1.1 EMG Controlled Prostheses

EMG signals generated from the remnant muscles of the amputee are collected through an EMG Acquisition System. Based on the EMG signals, the type of movement attempted by the user is identified in the EMG Recognition Module using signal processing and machine learning techniques. The information about the identified movement is passed to the Translation Module wherein a control is developed to command the prosthetic hand to emulate the identified movement.

1.1.1 Problems with EMG Controlled Prosthetic Hands

Although the concept of EMG controlled prosthesis has been known for several decades, there remain several issues to be addressed for its successful implementation. Despite serious research efforts, EMG based prosthetic hands (both commercial variants and research prototypes) are nowhere near to the original counterparts they intended to replace.

The lack of acceptance stems from an inadequate controllability. EMG based prostheses are non-intuitive in the sense that user is required to learn to associate muscle remnants action to unrelated postures of the prosthesis or being limited to few hand postures based on higher number of EMG channels. Most of the work on EMG based prosthesis control concentrates in EMG based classification of hand movements instead of correlated grasping for the control purpose.

Grasp is the interface between the subject’s hand and the object to be handled. A single grasp can perform different specific tasks. Such as a hook grasp can be used for pick and place operation of a mug as well as for pouring water from the mug; i.e. grasp are generic and task are specific in nature. For an effective extreme upper limb prosthesis, EMG based grasp classification holds promise (9). This thesis focus on the six grasp types as shown in Figure 1.2.

Even though classification of EMG signals has been the subject of considerable research; recognition has been either poor while using low channel EMG or only for a limited set of grasps based on higher number of EMG channels. EMG based grasp classification performance depends on type of features (10). Therefore, derivation of a feature vector resulting in higher recognition rate of grasp types based on lower number of EMG channels is one of the important issues.

Another important reason for non-acceptance of prosthetic hands by the amputees is their non-anthropomorphism. Present prosthesis are far from human hand in terms
1.2 Objectives

The work presented in this thesis stems from the desire to develop a biomimetic hand with EMG based grasp emulation. Although the use of advanced machine learning and signal processing techniques have proved useful in EMG based prostheses; higher recognition rate of grasp types based on low number of EMG channels is still a challenge. Eventhough multifingered hand prostheses using surface EMG (1), (13) have appeared in the market and advanced research prototypes (2), (14), (15), (16) have been developed; they are far from the human hand in terms of the functional geometry as well as controllability. A recognition architecture for grasp types used during daily living activities (dla) based on low number of EMG channels along with the development of a biomimetic hand emulating the recognized grasps holds promise. The prime objectives in this research include:

- Recognition of six grasp types (shown in Figure 1.2) involved during 70% of dla based on two channel EMG signals - derivation of a low dimensional yet informative and distinguishing feature vector through exploration of time domain, frequency domain and time/ frequency domain feature sets.

*Figure 1.2: Grasp types: a. Power b. Palm-up c. Hook d. Oblique e. Precision and f. Pinch. These six grasp types are significant for they are involved in 70% of dla (17)*
1.3 Thesis Outline

- Development of a biomimetic hand - a five fingered extreme upper limb inspired by human hand anatomy capable of emulating the above grasps based on EMG signals through a biomimetic approach satisfying the static and dynamic constraints of the human hand.

This thesis, however, does not address the issues for embedment of the control architecture for the biomimetic hand. The embedment of the EMG acquisition unit, control architecture as well as customization of the power supply are not within the purview of this thesis. Research is limited to the development of an extreme upper limb prototype emulating the grasp types based on EMG signals. To evaluate or compare prosthesis based on their conceptual closeness to the human hand, I have also worked on the following:

- Development of an anthropomorphic similarity index for evaluation of anthropomorphism of the biomimetic hand prototype - evolve a framework for quantification of anthropomorphism for prosthetic hands.

1.3 Thesis Outline

The remainder of this thesis is divided into six chapters and the content of each is summarised below in order to simplify the reading.

Chapter 2: Background and Literature Review

Prior to presenting the development of a biomimetic hand with EMG based grasp emulation and its evaluation, it is useful to have a historical perspective. This chapter provides the basic concepts of EMG signals and the literature review on the major components of this thesis: (a) EMG signals and its features for classification of hand gestures and grasp types, (b) human hand including its characteristics during grasping operations (c) commercially available prosthetic hands and research prototypes and (d) EMG based control for prosthetic hand operations.

Chapter 3: EMG based Grasps Recognition: Initial Results

This chapter begins by discussing the materials and methods followed for acquisition of EMG signals. The initial results on grasp classification are presented. Three grasps classification architecture developed for recognition of six grasp types are described. Entropy as a measure to find the closeness of a mother wavelet function coefficients with the grasp types is reported. Also sum of wavelet decomposition coefficients has
been established as a primal feature for grasp recognition.

Chapter 4: EMG based Grasps Recognition: Results with Statistical Analysis
Following the initial work on EMG based grasp recognition for six grasp types reported in chapter 3, this chapter proposes grasp recognition architecture-IV. The focus is on the derivation of a low dimensional yet informative and distinguishing feature set to significantly increase the performance of grasp types recognition based on lower number of EMG channels. A recognition rate of 97.5% is reported using principal components of discrete wavelet transform based EMG features. The recognition rate obtained is comparable to that reported in literature and better in terms of number of grasp types vis-a-vis number of EMG channels. The experimental results are statistically evaluated through analysis of variance and Sheffe’s post hoc test.

Chapter 5: A Biomimetic Hand: Prototype 1.0
Development of a biomimetic hand: Prototype 1.0 inspired by human hand anatomy is described in this chapter. A comparison of Prototype 1.0 vis-a-vis the human hand is presented. The kinematic, static and dynamic analysis of Prototype 1.0 satisfying the dynamic constraints of human hand is presented. This chapter also presents a two layered control architecture comprising of superior hand control (SHC) and local hand control (LHC) for the developed prototype. The SHC is to perceive the type of grasps attempted by the user based on the results reported in Chapter 4. The LHC is for emulating the identified grasp type into Prototype 1.0.

Chapter 6: Characteristics of Prototype 1.0 and A BSI
In this chapter, the performance requirements of the prostheses and Prototype 1.0 based on the research in prosthetic hands and their clinical use are set forth. A framework for quantification of anthropomorphism leading to a biomimetic similarity index (BSI) for prosthetic hands is proposed. Prototype 1.0 has been compared with five fairly established prosthetic hands with reference to human hand through the BSI.

Chapter 7: Conclusions and Future Work
It summarize the work presented in Chapter 2 through Chapter 6 with the concluding remarks. The issues to be encountered for further development of Prototype 1.0 are mentioned leading to future orientation of this research.