PREFACE

The thesis work presents the step-by-step procedure needed to be adopted to develop and evaluate robust below-knee prosthesis based on an adaptive intent recognition system that continually incorporates neural information through (i) electromyography (EMG) and (ii) kinetic and kinematic information acquired through mechanical sensors. Different aspects of designing lower limb prostheses have been studied to achieve this goal, including the human gait analysis for different terrains. The primary social utilization of this work is to help the amputee those are living in hilly areas. Further, for comparative analysis, a gait study has been performed by experimenting on healthy persons using wearable sensors for five different walking patterns: (i) level ground, (ii) ramp ascent, (iii) ramp descent, (iv) stair ascent, and (v) stair descent. The present study compares and presents prosthetic devices proposed or available to date for lower limb amputees, mainly ankle-foot prostheses.

After the broad overview and literature survey, the thesis can be divided into two major parts. First, the thesis work focuses on the gait analysis and gait phase detection techniques used in real-time to generate the control signal for the prosthetic leg. Different types of sensors are used and compared to provide real-time detection using different algorithms such as thresholding, heuristics rules, fuzzy logic, and machine learning (ML) approaches. In the second part, the thesis work presents different control strategies for the actuators and dampers used to design and develop a powered ankle-foot prosthesis prototype. The research work focuses on designing power ankle-foot prostheses, which can be afforded by middle-class amputees living in developing countries like India to mimic human-like movement. Of course, the design must be lightweight, battery-operated, and the controller operation in real-time.

Chapter 1 presents the introduction of the thesis, which states the current issues, objectives, and thesis contributions. Chapter 2 discusses the literature background for gait phase detection using different kinds of sensors and algorithms. The chapter explains the applications of gait analysis, the major focus in realizing the prosthetic foot to mimic human locomotion. This chapter also briefs the literature survey about different types of prosthetic foot in the market. Various ML algorithms are also introduced, later tested on healthy and amputee subjects in later chapters.

Chapter 3 introduces different ML algorithms for the classifications of human locomotion in five different terrains: Level Ground, Ramp Ascent, Ramp Descent, Stair Ascent, and Stair Descent. Hybrid sensor (EMG and accelerometer) technology is used in the proposed work to record the signal from two leg muscles: tibialis anterior and medial gastrocnemius for each leg. In chapter 4, Force-sensitive resistor (FSR) and inertial measurement unit (IMU) sensors are used to detect the gait phase in real-time; later, these are correlated with EMG signals for the above five terrains. The heuristic rules, zero-crossing, and fuzzy logic algorithms are employed for gait phase detection. MATLAB's Neuro-Fuzzy toolbox is used for the training purpose using labeled data that later predict the current gait phase.

Chapter 5 presents the different ML techniques to classify the following foot movements: dorsiflexion, plantarflexion, inversion, eversion, medial rotation, and lateral rotation. The purpose is to design a real-time standalone computing system to predict the foot movements in the sagittal plane, useful for ankle-foot prosthesis control. The present study acquires EMG and force-myography (FMG) signals from the leg's tibialis anterior, medial gastrocnemius, lateral gastrocnemius, and peroneus longus muscles. These are tested for their suitability to provide ML/ TinyML based control options to control prosthetic devices. The response of two kinds of processors, i.e., Raspberry Pi and Arduino Nano 33 BLE, is compared for real-time prediction.

Here the Arduino Nano controller has the limitation of memory; for overcoming this limitation, the latest Arduino Nano 33 BLE controller is suggested that can store more rules. Also, it is comparatively faster in performance when we focused on real-time applications. This chapter also includes the performance of fuzzy logic controllers for the ankle-foot movement classification problem of the previous chapter using EMG and FMG signals.

Further, Chapter 6 proposes designing and developing an ankle-foot prosthesis prototype using magnetorheological damper and 3D printer technology. The CAD model of the prosthetic foot, leaf spring, retention spring, and the various connecting parts required to connect the pylon and damper actuator assemblies are designed using CAD software. The fused deposition modeling 3D printer-based technique prints a prosthetic foot and other connecting parts using ABS filament. The prototype consists of two control parts: the first part controls the magnetorheological actuator that absorbs the impacts during walking. The second part is the control of the electric actuator intended to generate the dorsiflexion and plantarflexion movements. Finally, the prototype is tested on a transtibial amputee under the supervision of a prosthetist. In Chapter 7, the overall thesis contribution has been enlisted along with its future directions. It might be beneficial for further research in this field.