# Soft Wearable Augmented Walking Suit with Pneumatic Gel Muscles and Stance Phase Detection System to Assist Gait

## Abstract

Lower limb of the human body is responsible for human locomotion and maintain a good quality of life. However, there are many cases of muscle fatigue or injuries due to the stressful work environment, aging and work that involve walking a long distance. Therefore, there is a need for walking assistive suit which can unload muscle activation during walking and reduce the chances of lower limb muscle fatigue. In this paper we discuss the development of lightweight and wearable Augmented Walking Suit (AWS) using Pneumatic Gel Muscle and its actuation control using lower limb pose detection mechanism by considering human gait cycle. The objective of this assistive suit is to reduce required muscle effort of posterior and anterior muscle during the swing phase of the gait cycle thereby making it easier to move forward. To evaluate the effects of the suit we tested this suit with random subjects and record surface EMG (sEMG) of 8 primary lower limb muscles for two level of assistive forces. The evaluation was done based on the sEMG signal envelope for each subject for a different level of assistive forces and the statistical difference in percentage maximum voluntary contraction (\%MVC) of 8 primary lower limb muscles active during the gait cycle. In our result, we found that all subjects showed no change or a statistically significant reduction in muscle efforts due to assistive suit for all the muscles responsible for swing phase of the gait cycle.

## Introduction

Ability to move uninterrupted is one of the critical function of human body. It is one of the reasons for enjoying a good quality of life by enabling one to be independent for performing a variety of daily tasks. However, there are many instances such as aging, accidents and longer and more stressful working conditions that result in muscle fatigue and injuries making it difficult to walk by affecting the quality of life of the individual. Such situation can be avoided or addressed using exoskeletons or wearable assistive devices. Muscle activation pattern of human gait is dynamic, and changes as the motion or intent are changed, but the basic pattern of gait cycle is same for all. While developing AWS we considered factors such as nature of work area, age, flexibility to use in outside environment, lightweight, portable, easy to use, reduces muscle efforts during walking and no impact on normal gait cycle. With increasing elderly population, stressful work condition devices like these will play a significant role in improving the quality of life. L. Garçon et al. \cite{1} in his review mentioned there are large requirement assistive devices for mobility for people such as elderly, disabled and healthcare staff for various tasks involved in daily life. Among various lower limb assistive devices, there exists tradeoff between autonomous actuation, wearable, lightweight and affordability. HAL \cite{2} which enable walking easier for elderly and rehabilitation post stroke or accidents. Wearable agri robot \cite{3} designed for supporting farming activities and reduce muscle fatigue, it supports body posture and reduces the muscle fatigue. Walking assist device with body weight support system \cite{4} for augmenting walking and assistive squats motion required for pick and place tasks in the various work environment. RoboKnee \cite{5} is one DOF exoskeleton designed to support human locomotion such as walk and stair climbing. Plantarflexion assist exoskeleton \cite{6} is designed to reduce the metabolic cost of walking.

These devices are divided into segments such as healthcare, disability support and augmenting locomotion. These devices augment human motion significantly, but its use in outside environment is limited especially in agriculture and factory settings. For augmented walking wearable, lightweight, portable, easy to use and reduce muscle fatigue, these criteria are essential and together missing in assistive devices discussed above. To solve this problem previously, we developed a lightweight, low powered pneumatic gel muscle (PGM) \cite{7} as shown in Fig \ref{fig:pgm}. PGM can generate force with 60 kPa air pressure which is not possible in McKibben pneumatic artificial muscle (PAM) \cite{8}. It is also structure in a way to be stitched to fabric or fix using velcro tapes; this makes it easy to design the assistive suit. Fig \ref{fig:pgmelongationratio} shows the relation of supplied air pressure, generated force and maximum elongation as a percentage of resting length.

In \cite{9} we devised the concept if Unplugged Powered Suit for walking assist using the advantage of PGM and gait cycle. The actuation control of PGM was designed by attaching pump at the heel of a shoe. This configuration was able to generate minimal assistive force for walking. However, the challenge of this configuration changes in shoe design and placement of pumps in the shoe for generation of assistive force.

In this paper, we discuss the design and control of AWS, which improves on Unplugged Powered Suit (UPS) by keeping human gait in the loop by using gait cycle identification system for generating assistive force. In section \ref{methodology} PGM and its force characteristics, biomechanics and human gait detection system and design and configuration of the Augmented walking suit is discussed. In section \ref{Evaluation}, we discuss the evaluation criteria, experiment method setups, results of the lower limb surface EMG (sEMG) evaluation for two levels of assistive force with the comparison of average gait sEMG envelope for all subjects and statistical analysis. Section \ref{discuss} presents the discussion, conclusion and future works.