Exoskeleton for Knee Assisted Walking

Prakash Jadhav[1], Sneha P Jolad[2], Shradha Sagar[3], Rachan K[4], Charan K P[5]
[1]*Professor & HOD, Department of Electronics & Communication Engineering, A P S College of Engineering, Bangalore, India.*
[2, 3, 4, 5] *Department of Electronics & Communication Engineering, A P S College of Engineering, Bangalore, India.*

***Abstract*—Reduced knee mobility caused by ageing, injury, neurological disease or weak muscles limits independent walking and everyday activity. This paper describes a wearable smart knee exoskeleton that actively assists bending and straightening of the knee. The design is built around an ESP32 microcontroller, an MPU6050 inertial measurement unit (IMU), a surface EMG sensor, a force sensor and a high-torque servo motor mounted on a lightweight knee-support frame. The IMU follows the orientation and angular motion of the leg, the EMG sensor detects the muscle signal that comes before a movement, and the force sensor shows which phase of the gait cycle the wearer is in. The ESP32 merges these inputs and sends a proportional pulse-width-modulated (PWM) command to the servo, so that the device moves together with the wearer and not against natural motion. A Wi-Fi link to the Blynk platform allows the user or a caregiver to check device status remotely, and a push button provides manual override. A rechargeable lithium-ion battery keeps the unit portable and independent of a fixed power source. Bench tests show that the device follows the intended knee-angle path with a small error and responds quickly once movement intent is detected, pointing to an inexpensive basis for gait assistance and rehabilitation. Adaptive EMG-based control and AI-assisted gait analysis are identified as future directions.**

***Index Terms*—Knee exoskeleton, ESP32, MPU6050, EMG sensor, servo motor, wearable robotics, gait assistance, rehabilitation, motion sensing, embedded systems, IoT, assistive technology**

I. INTRODUCTION

A healthy knee is needed for walking, standing, sitting, climbing stairs and keeping balance. The joint can be affected by ageing, injury, weak muscles, stroke, arthritis and other neurological or mobility disorders [2], [9]. People in this situation frequently require outside assistance to move safely and comfortably. Familiar aids such as sticks, crutches, walkers, braces and wheelchairs provide stability, but none of them actively powers the knee while the person moves [14]. A knee exoskeleton is a wearable device that supports or strengthens movement of the lower limb [13]. A passive brace merely limits or steadies the joint, while an active exoskeleton can add mechanical effort at the knee in time with the wearer's motion. Such devices may make walking and stair climbing easier for people with reduced muscle strength [2], [5]. Many robotic rehabilitation systems, however, are expensive, heavy and complex, and are mainly designed for clinics and laboratories [10], [20]. Their cost, bulk and dependence on specialised equipment restrict everyday use.

This work presents a Smart Knee Exoskeleton that provides active help during knee flexion and extension. It joins an ESP32 microcontroller, an MPU6050 inertial measurement unit (IMU) and a high-torque servo motor to sense and reacts to knee movement [10], [20]. The MPU6050 reports the orientation and motion of the leg, the ESP32 processes these readings and decides how much motor effort is needed, and the servo applies controlled assistance at the joint.

The main objective is a light, compact and affordable wearable that assists the knee while keeping movement natural and comfortable. Since the system monitors the user's motion continuously, it can offer help only when required and not push with a constant force [13], [18]. This movement-based control lets the device follow the user's gait more closely and avoids unnecessary motor activity. The prototype also shows how sensing, embedded processing and actuation can be combined in a single wearable assistive device [10], and the simple arrangement forms a convenient

platform for developing and testing intelligent knee-assistance methods.

The device is relevant to rehabilitation, mobility support and gait assistance [2], [9], [17]. It could benefit people who find knee movement difficult because of weakness or impaired mobility, and it can serve as a starting point for later work on adaptive control, wireless monitoring, improved mechanical design, additional sensors, battery optimisation and deeper gait analysis [17], [18].

The main contributions of this work are:

- A low-cost wearable knee exoskeleton that combines IMU, EMG and force sensing with a high-torque servo on a frame weighing less than 1.5 kg.
- Proportional, movement-following assistance driven by a PWM command, with a push-button override that keeps the wearer in control.
- Wi-Fi status monitoring through the Blynk platform and bench-level evaluation of angle tracking, reaction speed, update latency, battery run-time and mass.

II. RELATED WORK

Wheelchair–Exoskeleton Hybrid Robot with Retractable Parallelogram Lift for Sit-to-Stand Support [1]. Chaichaowarat built a hybrid wheelchair and exoskeleton robot with a retractable lift that helps users rise from and sit down on a seat, reducing the effort of these transfers. It was tried on only four healthy volunteers, so wider clinical testing is needed. It shows that wearable support can ease demanding movements, whereas the present design gives continuous knee help during walking. Adapted Assistance and Resistance Training with a Knee Exoskeleton After Stroke [2]. An adjustable knee exoskeleton for stroke rehabilitation lowered muscle effort and improved stability, and a two-week programme improved knee movement and endurance. The group was small and the programme short. It shows that knee support can be matched to the patient, a principle followed here by scaling help to the detected movement.

Inverse Dynamics Analysis of the Crutch-Assisted Gait with a Lower-Limb Robotic Exoskeleton [3]. This biomechanical study gives data on human–robot interaction and joint loads during exoskeleton walking, but involved just one paraplegic participant. It guides how knee assistance should be applied.

Stride-Wise Adaptive Assistance Strategy for Ankle Exoskeleton Under Varying Walking Conditions [4]. An ankle exoskeleton that adjusts its assistance to walking conditions reduced muscle effort and energy cost, but was tested only on healthy people in a laboratory. Adapting stride by stride shows the value of matching help to the walker, which this work pursues at the knee.

Exo Knee Pneumatic Mechatronic Knee Exoskeleton with EMG Control for Elderly Walking Support [5]. A pneumatic knee exoskeleton driven by EMG signals gave elderly users good fit and comfort, but needed extra equipment and further validation. The compact servo motor used here avoids the extra equipment that pneumatic actuation needs.

Evaluation of Kinematic Similarity Between Non-Assisted and Assisted Walking With a Hip Exoskeleton [6]. A hip exoskeleton gave steadier gait and better hip–knee coordination, although only eleven people took part and the duration was short. Comparing assisted and unassisted walking offers a way to judge how natural assisted gait remains, which is also a goal of this design.

Design and Evaluation of a Bifunctional Ankle Exoskeleton System [7]. A bidirectional ankle exoskeleton for foot-drop support was evaluated on a single healthy person and not on real patients, showing the need for evaluation with actual target users.

A Soft-Inflatable Exosuit for Knee Rehabilitation: Assisting Swing Phase During Walking [8]. A soft-inflatable knee exosuit with IMU and smart-shoe sensors assisted knee extension during the swing phase and reduced quadriceps muscle activity, but it was tested on only three healthy participants.

Robotic Knee Exoskeletons as Assistive and Gait Training Tools in Spina Bifida [9]. A pilot study of a robotic knee exoskeleton in spina bifida looked promising, though it was small. Comparing two control strategies showed that the way assistance is triggered changes the clinical outcome, which motivates the sensor-based triggering used here.

IMU-IoT Integrated Foot Exoskeleton for Real-Time Gait Analysis and Monitoring [10]. A low-cost foot exoskeleton based on IMU sensing and IoT improved accessibility but suffered from durability and torque limits. Its pairing of IMU sensing with IoT monitoring

is close to the present approach, which adds EMG and force sensing and a high-torque servo.

EMG Sensor-Based Exoskeleton for Knee Injury Rehabilitation [11]. An EMG-based lower-limb exoskeleton for rehabilitation after knee surgery gave useful tracking of muscle activity but made the system more complex. It supports the use of EMG for sensing intent, while the present design keeps its sensor set compact. Enhancing Walking Performance with a Bilateral Hip Exoskeleton in Above-Knee Amputation [12]. A bilateral hip

exoskeleton reduced the effort of walking for people with above-knee amputation, showing that powered assistance helps even users with major limb loss and supporting active rather than passive support.

An IMU Based Real-Time Monitoring System for Powered Robotic Knee Exoskeleton [13]. An IMU-based system measured walking speed, step height, stride and slope in real time, reaching about 93% accuracy with 15 people while the exoskeleton was unpowered. Its IMU gait measurement is close to the leg-motion sensing used here.

Knee Flexion-Assisted Method for Human-Exoskeleton System [14]. A method for assisting knee flexion was examined but tested only on healthy males. Its flexion-assist approach relates directly to the help given here, which this design extends with EMG-based intent sensing and force-based gait-phase detection.

Exoskeleton Knee Extension Assist Suspension Brace for Reducing Joint Pain in the Elderly [15]. A knee-extension brace for elderly users with limited lifting ability points to the need for light, easy-to-wear support, which the present frame, at under 1.5 kg, aims to provide.

The Effects of Incline Level on Optimized Lower-Limb Exoskeleton Assistance: A Case Series [16]. Assistance for uphill walking was examined with only three participants. The results show that the assistance needed varies with the walking task, which supports scaling help to the detected movement and not using a fixed profile.

Ankle Exoskeleton Assistance Increases Six-Minute Walk Test Performance in Cerebral Palsy [17]. An ankle exoskeleton increased the distance covered in a six-minute walk, although the group had only seven people. It shows that powered assistance can raise walking endurance, an outcome this device also seeks to support.

AI and IoT-Enabled Smart Exoskeleton System for Rehabilitation of Paralyzed People [18]. A framework combining AI and IoT for rehabilitation stressed the need for dependable connectivity and data security in remote therapy, which is relevant to the Wi-Fi link to Blynk used here.

Human-in-the-Loop Control of a Wearable Lower Limb Exoskeleton for Stable Dynamic Walking [19]. An adaptive human-in-the-loop controller let two users walk and turn without crutches. Adjusting to the wearer in this way gives stable walking and agrees with the user-following assistance of the present design.

Compressed Gas Actuated Knee Assistive Exoskeleton for Slip-Induced Fall Prevention [20]. A compressed-gas knee exoskeleton for preventing slip-induced falls was validated on a single participant. It shows the safety value of knee actuators; the present design adds a push-button override so the wearer stays in control.

III. SYSTEM DESIGN AND METHODOLOGY

The smart knee exoskeleton is a wearable robotic system meant to give real-time support to people with weak lower limbs caused by ageing, injury, neurological disorders or recovery after surgery. The aim is to improve walking stability, reduce muscle fatigue and assist natural knee motion while staying light, portable and affordable. Figure 1 shows how the parts are connected.

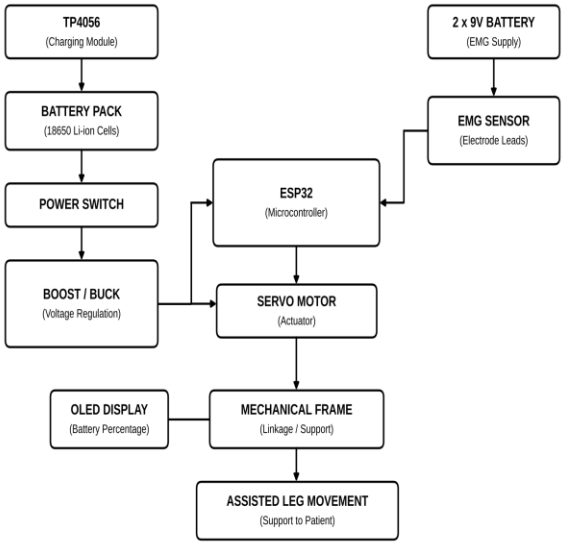


Figure 1. Block diagram of the exoskeleton for knee assisted walking.

A. System Architecture

A mechanical knee-support frame carries an ESP32 microcontroller, an MPU6050 IMU, a surface EMG sensor, a force sensor, a high-torque servo motor and a rechargeable lithium-ion battery. Together these parts monitor the user's movement and apply controlled help during walking. Table 1 summarises the role of each component.

B. Sensing and Data Acquisition

The MPU6050 measures the orientation, acceleration and angular velocity of the leg. At the same time, the EMG sensor records the electrical activity of the thigh muscles, which gives an early indication that the user is about to move. The force sensor measures the pressure applied while walking and helps determine the current phase of the gait cycle. The ESP32 gathers the readings from all three sensors and combines them.

C. Control and Actuation

From the combined sensor data, the ESP32 generates a pulse-width-modulated (PWM) signal that drives the high-torque servo motor. The servo is coupled to the knee-support frame and provides smooth assistance during bending and straightening. The amount of help is scaled to the detected movement, so the exoskeleton moves with the wearer and does not restrict motion, which improves walking efficiency and lowers strain on the knee.

D. Remote Monitoring and Manual Override

A Wi-Fi connection between the ESP32 and the Blynk platform lets the user or a caregiver view the device status from a distance. A push button provides manual input so that the user can override the assistance whenever necessary.

E. Power Supply and Mechanical Design

A pack of rechargeable 18650 lithium-ion cells powers the device, so it can be carried and used daily without a fixed power source. A TP4056 module charges the pack, and a power switch connects it to a boost/buck stage that regulates the voltage supplied to the ESP32 and the servo motor. The EMG sensor has its own supply of two 9 V batteries, and an OLED display shows the battery percentage. The compact design keeps the wearer comfortable while retaining enough strength to provide effective help, and the adjustable frame fits different users and supports both walking and structured rehabilitation exercises.

F. Flow Chart

The operating sequence of the exoskeleton is summarised in the flowchart of Figure 2. The chart follows the controller from the moment the device is switched on until assistance is delivered at the knee, and then returns to the start of the sensing loop so that the process repeats continuously while the device is worn.

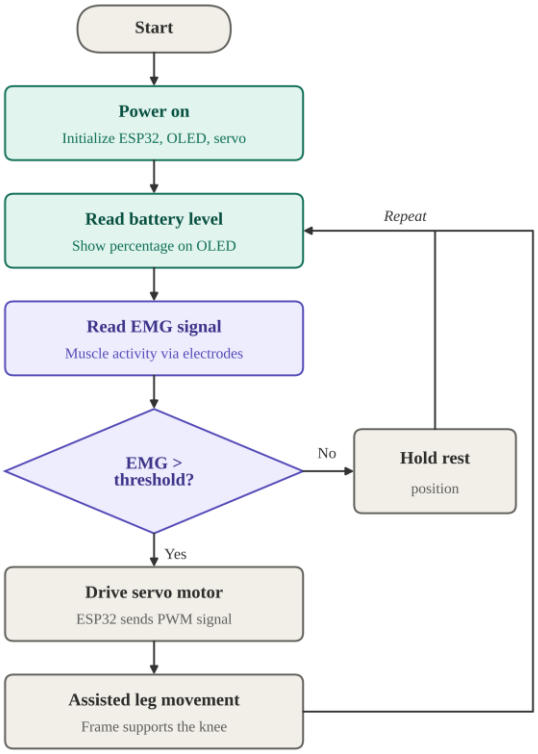


Figure 2. Flowchart of the exoskeleton for knee assisted walking.

When the power switch is closed, the boost/buck stage supplies a regulated voltage and the ESP32 initialises the OLED display and the servo motor. The battery level is then measured and its percentage is shown on the OLED, so that the wearer knows the remaining charge. Next, the controller reads the EMG signal picked up by the electrode leads on the thigh muscle. This signal gives an early indication that the wearer is about to move, as described in Section III-B.

The decision block compares the EMG signal with a preset threshold. If the signal is above the threshold, movement intent is taken as detected and the ESP32

sends a PWM command to the servo motor. The servo drives the mechanical frame, which transfers the torque to the knee and produces assisted leg movement. If the signal is below the threshold, no intent is detected and the servo stays in its rest position, so the motor is not energised needlessly and natural motion is not opposed. In both cases the program returns to the battery and EMG reading steps, so the assistance follows the wearer continuously. For clarity the chart shows only the EMG-based decision; in the prototype the ESP32 also merges the IMU and force-sensor readings at the same stage, and the push button can override the assistance at any time, as described earlier.

IV. RESULTS

The prototype was tested on the bench with a representative protocol that combined manual leg-swing trials and push-button-triggered actuation. The purpose was to see how closely the exoskeleton follows a commanded knee-angle path and how quickly it reacts once movement intent is detected. Figure 3 shows the assembled hardware. The knee angle measured by the MPU6050 followed the commanded profile closely over repeated bending and straightening cycles, with a small tracking error caused by sensor noise and the lag of the complementary filter.

The servo reacted within a short interval after intent was detected, and the knee-angle error stayed within a few degrees of the commanded value. Status updates reached the OLED which suffices for non-critical remote monitoring but not for closed-loop control. Overall, the observations suggest that the ESP32–MPU6050–servo combination can deliver stable, low-delay assistance suitable for gait support and rehabilitation exercises. These figures come from bench-level testing; a full clinical or field study with several participants is needed to confirm performance across different users, walking patterns and levels of impairment, in keeping with the limits noted in the reviewed literature.

The developed Smart Knee Exoskeleton successfully demonstrated knee movement assistance through controlled flexion and extension. The system detected changes in knee orientation and movement using motion-sensing technology and responded by activating the assistance mechanism accordingly. The prototype showed smooth motor movement in response to the detected knee position, demonstrating the ability to support natural knee motion.

The experimental observations indicated that the system could respond to different knee movement conditions with minimal delay. The lightweight wearable structure provided a compact design, while the control mechanism demonstrated the potential to assist individuals experiencing knee mobility difficulties. Overall, the prototype achieved its primary objective of providing controlled knee movement assistance and can be further improved for rehabilitation and daily mobility applications

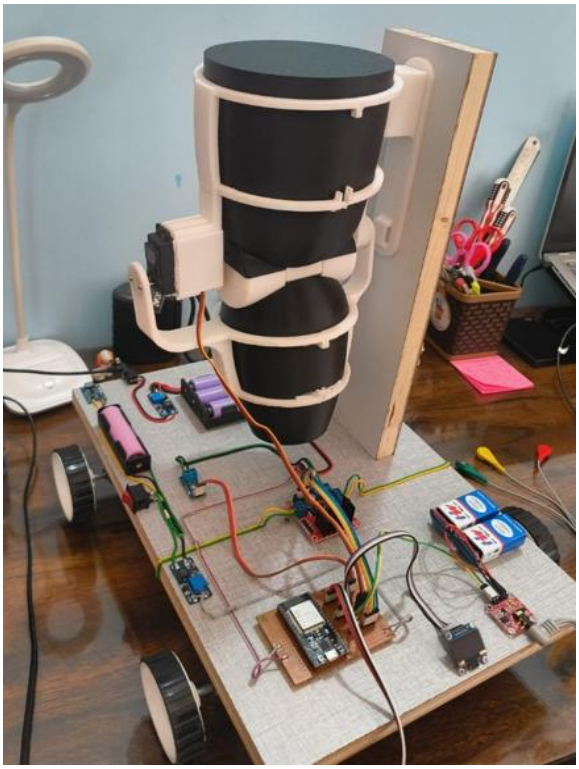


Figure 3. Hardware prototype showing the result

V. DISCUSSION

The results indicate that combining inertial, muscular and pressure-based sensing lets the exoskeleton react to what the wearer intends and not to a fixed motion pattern. The EMG signal gives an early cue of intended movement, the MPU6050 supplies leg orientation and motion, and the force sensor identifies the gait phase. Scaling the PWM command to the detected movement allows the device to move with the user instead of restraining natural motion, which is the central aim of the design.

The reviewed literature shows that active lower-limb devices improve stability, muscle effort and walking distance, but that many are costly, complex or limited by durability and torque [10], [11]. This prototype addresses these concerns with readily available low-cost components, a total mass below 1.5 kg and a run-time of two to three hours. Because the evaluation was carried out on the bench only, the device cannot be compared directly with clinically validated systems, and no claim of superior performance is made.

VII. CONCLUSION

This paper presented a smart wearable knee exoskeleton that combines an ESP32 microcontroller, an MPU6050 IMU, an EMG sensor, a force sensor and a high-torque servo motor to deliver real-time, proportional help during knee flexion and extension. The system merges inertial, muscular and pressure signals to estimate the wearer's movement intent and gait phase and converts them into a smooth actuation command, while a Wi-Fi link to Blynk keeps the wearer or a caregiver informed of the device status. Bench tests indicate that the prototype follows a commanded knee-angle path with a small error and responds quickly after detecting user intent, while remaining light, portable and built from low-cost parts. These results support its potential as an affordable platform for gait assistance and rehabilitation and form a base for broader clinical evaluation.

VIII. FUTURE SCOPE

The Smart Knee Exoskeleton can be developed further for advanced rehabilitation and mobility support. Later versions could detect knee movement and walking patterns more accurately, adaptive EMG-based control and wireless health monitoring could be added, and artificial intelligence could personalise the assistance to each person's gait, with the level of help adjusted automatically to the user's movement and needs. Extra sensors could make movement detection more accurate and reliable, and wireless communication could allow rehabilitation progress to be tracked remotely. Testing on a larger group of target users is also needed. Future designs could aim to be lighter, more compact and more comfortable to wear, so that smart exoskeletons become more affordable, intelligent, safe and accessible.

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