IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

NEUROSTRIDE-X: AN ADAPTIVE HUMAN–ROBOT PLATFORM FOR DYNAMIC BALANCE RECOVERY AND MOBILITY ASSISTANCE

[1]Dr.Jyoti R Maranur, [2]Mahalaxmi Y Sanka, [3]Anusha, [4]Kavya, [5]Eshwari M Patil

, [1]Associate Professor, [2-5]Students

[1-5]Computer Science & Engineering ,

[1-5]Sharnbasva University,Kalaburagi,Karnataka,India

Abstract: Robotic balance trainers have emerged as promising rehabilitation technologies for individuals affected by stroke, neurological disorders, age-related mobility decline, and other conditions that impair postural stability. This study presents NeuroStride-X, an adaptive human-robot platform designed to support dynamic balance recovery and mobility assistance through intelligent monitoring and controlled intervention. The proposed system integrates a mobile robotic base, a robotic support mechanism, ultrasonic sensing, Bluetooth communication, and a microcontroller-based control unit to assist users during standing and walking activities. The platform continuously observes body movement and stability conditions, providing support only when imbalance is detected, thereby encouraging natural motor responses and rehabilitation progress. The design emphasizes patient safety, fall prevention, reduced dependence on therapists, and suitability for home-based rehabilitation environments. Adaptive assistance enables improved confidence, mobility, and independence while supporting repetitive training essential for motor recovery. The system combines balance training and gait assistance within a single framework, addressing limitations of conventional rehabilitation methods. The proposed approach contributes toward accessible, cost-effective, and intelligent rehabilitation solutions for enhanced functional recovery outcomes.

Index Terms –NeuroStride-X, Robotic Balance Trainer, Human-Robot Interaction, Balance Rehabilitation, Mobility Assistance, Adaptive Control, Gait Training, Postural Stability, Rehabilitation Robotics, Assistive Technology.

I. INTRODUCTION

Human mobility and balance are essential for performing everyday activities such as standing, walking, turning, and reaching. The ability to maintain postural stability depends on the coordinated functioning of the nervous system, muscles, joints, and sensory mechanisms. However, conditions such as stroke, neurological disorders, spinal cord injuries, age-related impairments, and traumatic accidents can significantly affect balance control and mobility. These impairments often increase the risk of falls, reduce independence, and negatively impact the overall quality of life. As the global population ages and the prevalence of mobility-related disorders continues to rise, the demand for effective rehabilitation technologies has become increasingly important.Traditional rehabilitation approaches mainly rely on physiotherapy sessions conducted under the supervision of trained therapists. Although these methods are beneficial, they are often limited by high costs, restricted therapy duration, therapist availability, and the lack of continuous training opportunities. Patients frequently face challenges in transferring rehabilitation skills learned in clinical settings to real-world environments, which can slow recovery and reduce confidence during daily activities. Consequently, there is a growing need for intelligent systems capable of providing safe, continuous, and adaptive rehabilitation support.Robotic balance trainers have emerged as a promising solution to address these challenges by combining robotics, sensing technologies, and rehabilitation principles. These systems assist individuals during balance and mobility exercises while ensuring safety and reducing dependence on constant therapist supervision. Advances in rehabilitation robotics have enabled the development of devices that monitor movement, detect instability, and provide controlled assistance when required. Such technologies support repetitive training, encourage natural motor responses, and contribute to improved functional recovery.NeuroStride-X is an adaptive human-robot platform developed to enhance balance recovery and mobility assistance for individuals with balance impairments. The system integrates a mobile robotic base, intelligent sensing mechanisms, wireless communication, and a robotic support structure to assist users during standing and walking activities. By continuously monitoring movement and providing support only when instability is detected, the platform promotes safe rehabilitation while encouraging independent motion. The proposed system aims to improve patient safety, reduce fall risks, support home-based rehabilitation, and enhance mobility outcomes through intelligent and adaptive robotic assistance.

II. Related Works

Article [1]: "Balance Rehabilitation through Robot-Assisted Gait Training in Post-Stroke Patients: A Systematic Review and Meta-Analysis" by Alberto Loro, Margherita Beatrice Borg, Marco Battaglia et al. in 2023: The authors conducted a systematic review and meta-analysis to evaluate the effectiveness of robot-assisted gait training for balance rehabilitation in post-stroke patients. Multiple clinical studies were analyzed to assess improvements in balance, mobility, and functional recovery. The findings indicated that robotic rehabilitation systems provide repetitive and controlled training sessions that enhance postural stability. The study highlighted significant improvements in balance performance when robotic training was combined with conventional therapy. The research emphasized patient safety and reduced fall risks during rehabilitation.

Article [2]: "The Effect of Robotic Assisted Gait Training With Lokomat on Balance Control After Stroke: Systematic Review and Meta-Analysis" by Francesco Baronchelli, Alessandro Zucchella, Cristina Serrao et al. in 2021: This study investigated the impact of Lokomat-based robotic gait training on balance recovery in stroke survivors. The authors analyzed multiple rehabilitation studies involving robotic assistance and conventional physiotherapy. Results showed that robotic gait training produced positive effects on balance improvement and walking performance. The research demonstrated that repetitive robotic movement can improve motor learning and postural control. The study also discussed the importance of task-specific rehabilitation exercises. Findings suggested that robotic systems can achieve outcomes comparable to traditional therapy.

Article [3]: "Graceful User Following for Mobile Balance Assistive Robot in Daily Activities Assistance" by Yifan Wang, Meng Yuan, Lei Li, Karen Sui Geok Chua, Seng Kwee Wee, and Wei Tech Ang in 2023: This paper introduced a Mobile Robotic Balance Assistant designed to support balance-impaired individuals during daily activities. The system incorporates a three-degree-of-freedom robotic arm and an intelligent mobile base. A user-following control algorithm was developed to track human movement smoothly and accurately. The robot provides balance assistance while minimizing interference with natural gait patterns. The study focused on home-based rehabilitation and daily living support. Simulation results demonstrated stable operation under different walking conditions.

Article [4]: "Mobile Robotic Balance Assistant (MRBA): A Gait Assistive and Fall Intervention Robot for Daily Living" by Lei Li, Wei Tech Ang, Yifan Wang et al. in 2023: The authors presented a mobile robotic platform capable of assisting individuals with impaired balance during walking and daily activities. The robot follows the user and provides support at the pelvic region whenever instability occurs. The design focused on reducing fall risks and increasing mobility independence. The study integrated robotic mobility, sensing technologies, and balance intervention mechanisms. Experimental evaluation demonstrated effective support during gait activities. The robot was suitable for both rehabilitation exercises and daily assistance.

Article [5]: "Effectiveness of Robot-Assisted Lower Limb Rehabilitation on Balance in People with Stroke: A Systematic Review, Meta-Analysis, and Meta-Regression" by Riikka Yli-Ikkelä, Antti Rintala, Anni Köyhäjoki, Hanna Hakonen, Hanna Korpi, and Minna Kantola in 2023: This research analyzed the effectiveness of robot-assisted lower-limb rehabilitation in stroke patients. The study evaluated balance improvement across multiple rehabilitation programs. Results indicated that robotic rehabilitation can significantly improve balance and mobility outcomes. The authors reported better recovery rates in acute-stage patients. The study highlighted the safety and reliability of robotic rehabilitation methods. Meta-analysis results demonstrated measurable improvements in postural stability.

Article [6]: "Effect of the Robot-Assisted Gait Training Frequency on Balance and Gait in Stroke Patients in Convalescent Rehabilitation Hospitals: A Preliminary Study" by Moo-Hong Yoon, Bong-Sik Woo, Yong-Hwa Park, Dae-Hwan Lee, Eung-Sung Kim, Jin-Ook Choi, Jong-Hyeon Lim, Dae-Seong Han, and Tae-lim Yoon in 2024: This study examined how different frequencies of robot-assisted gait training influence balance and gait recovery. The researchers evaluated stroke patients undergoing rehabilitation in clinical environments. Results showed that training frequency plays a critical role in rehabilitation outcomes. Increased robotic training sessions improved walking ability and balance performance. The study emphasized personalized rehabilitation planning. The authors highlighted the importance of optimizing robotic therapy schedules. Findings suggested improved recovery efficiency through structured robotic intervention.

Article [7]: "How Robot-Assisted Gait Training Affects Gait Ability, Balance, and Functional Recovery After Stroke: A Systematic Review" by Ji-Hoon Lee and colleagues in 2024: This review examined the impact of robotic gait training on stroke rehabilitation outcomes. The study assessed balance, gait performance, and functional independence. Findings indicated that robotic rehabilitation has considerable potential for improving walking ability. The research demonstrated positive effects on balance recovery and motor function. Various robotic systems were evaluated across multiple rehabilitation settings. The study highlighted the importance of repetitive and intensive training.

Article [8]: "Equilivest: A Robotic Vest to Aid in Post-Stroke Dynamic Balance Rehabilitation" by Franco Paviotti, Esteban Buniak, Rodrigo Ramele, Orestes Freixes, and Juan Miguel Santos in 2023: The authors developed a robotic smart vest designed to assist dynamic balance rehabilitation after stroke. The system used inertial measurement sensors to monitor body movement. Vibrotactile feedback was provided to improve balance awareness and posture control. Different rehabilitation modes were incorporated to support patient-specific therapy. The device aimed to improve functional recovery through real-time feedback. The study emphasized wearable rehabilitation technology..

Article [9]: "Identifying Best Fall-Related Balance Factors and Robotic Rehabilitation Strategies for Stroke Survivors" by H. Kim and colleagues in 2024: This research investigated the relationship between fall-related factors and robotic rehabilitation strategies. The study focused on improving balance assessment and fall prevention methods. Researchers analyzed various balance parameters associated with rehabilitation outcomes. The findings highlighted key indicators that influence recovery and mobility performance. Robotic interventions were evaluated for effectiveness in reducing fall risks. The study emphasized personalized rehabilitation planning.

Article [10]: "Research on a New Rehabilitation Robot for Balance Training and Assessment" by J. Wu and colleagues in 2023: This paper proposed a rehabilitation robot designed specifically for balance training and performance assessment. The system incorporated sensors to measure posture, movement, and stability. Experimental results demonstrated accurate balance monitoring capabilities. The robot provided controlled assistance during rehabilitation exercises. The study focused on improving patient safety and rehabilitation effectiveness. Real-time feedback mechanisms enhanced training quality. The proposed platform reduced dependence on manual supervision. The research contributes toward intelligent rehabilitation robotics development.

Article [11]: "Comparison of the Use and Training Effects of Two Types of Robot-Assisted Gait Training Systems in Stroke Rehabilitation" by Taizan Shirakawa and colleagues in 2024: This study compared two different robotic gait training systems used in stroke rehabilitation. The researchers analyzed walking independence, balance ability, and daily activity performance. Results demonstrated that robotic systems can significantly enhance functional recovery. Different patient groups benefited from different robotic approaches. The study emphasized selecting rehabilitation technologies based on patient needs. Improvements in balance and mobility were observed across both systems.

Article [12]: "Assistive Robot Teleoperation Using Behavior Trees" by Mohamed Behery, Minh Trinh, Christian Brecher, and Gerhard Lakemeyer in 2023: This research focused on assistive robotic systems capable of supporting human activities through intelligent teleoperation. The authors introduced behavior-tree-based control methods for robotic assistance. The system improved task execution through adaptive shared-control mechanisms. Obstacle avoidance and trajectory guidance were integrated into the design. The research highlighted the importance of user-centered robotic assistance. Experimental evaluations demonstrated reliable performance in assistive applications.

III. Problem Stetement

Individuals affected by stroke, neurological disorders, spinal cord injuries, aging, and mobility impairments often experience significant difficulties in maintaining balance and performing daily activities independently. Conventional rehabilitation methods require continuous therapist supervision, offer limited training duration, and are generally confined to clinical environments. Existing rehabilitation systems are often expensive, bulky, and focused on either gait training or balance training rather than both simultaneously. The lack of portable and adaptive rehabilitation solutions increases the risk of falls and restricts long-term recovery. Therefore, there is a need for an intelligent system capable of providing safe, continuous, and real-time balance assistance while supporting mobility and rehabilitation in everyday environments.

IV. Objectives

The primary objective of this study is to develop NeuroStride-X, an adaptive human-robot platform that assists individuals with balance and mobility impairments during rehabilitation. The system aims to provide intelligent support for standing and walking activities while improving postural stability and reducing the risk of falls. Another objective is to integrate mobility assistance and balance training within a single platform to enhance rehabilitation effectiveness. The study also focuses on promoting patient independence, minimizing dependence on therapists, supporting home-based rehabilitation, and enabling safe real-time monitoring of movement. Additionally, it seeks to improve functional recovery, mobility confidence, and overall quality of life.

V. Methodology

1)Data Acquisition and User Monitoring: The methodology begins with continuous monitoring of the user's movement and balance conditions. Sensors are used to collect information related to posture, motion, and body stability during standing and walking activities. The acquired data helps in understanding the current physical state of the user. Continuous observation ensures timely detection of instability and supports safe rehabilitation assistance.

2) Balance Assessment and Analysis: The collected sensor data is analyzed to determine the user's balance condition in real time. Parameters such as body orientation, movement patterns, and stability levels are evaluated. The system identifies deviations from normal balance conditions and assesses the risk of falls. This analysis forms the basis for intelligent decision-making and adaptive assistance.

3)Mobile Robotic Base Operation: The mobile robotic base is responsible for moving along with the user during rehabilitation activities. It maintains proper alignment and positioning to ensure effective support throughout the training process. The platform enables smooth navigation in different environments while providing stability. This mobility allows rehabilitation exercises to be performed beyond clinical settings.

4)Adaptive Assistance Mechanism: An adaptive control mechanism determines when assistance is required based on balance assessment results. Support is provided only when instability exceeds predefined safety limits. This approach encourages natural movement and active patient participation during rehabilitation. Adaptive intervention improves motor learning while maintaining user safety.

5)Robotic Support and Stability Control: The robotic support structure provides physical assistance to maintain balance during standing and walking tasks. Controlled movements are used to stabilize the user whenever loss of balance is detected. The support mechanism helps prevent falls and reduces the risk of injury. Smooth assistance ensures comfort and effective rehabilitation outcomes.

6)Communication and System Control: Wireless communication modules enable seamless interaction between system components and control interfaces. Commands and sensor information are transmitted efficiently to support real-time operation. The control unit processes incoming data and coordinates the actions of the robotic platform. This integration enhances responsiveness and system reliability during rehabilitation sessions.

7)Rehabilitation Performance Evaluation: The final stage involves evaluating rehabilitation performance based on user stability, mobility improvement, and system effectiveness. Data collected during training sessions is analyzed to assess progress over time. Performance evaluation helps identify areas requiring further improvement. The results contribute to optimizing rehabilitation strategies and enhancing overall recovery outcomes.

VI. SYSTEM ARCHITECTURE

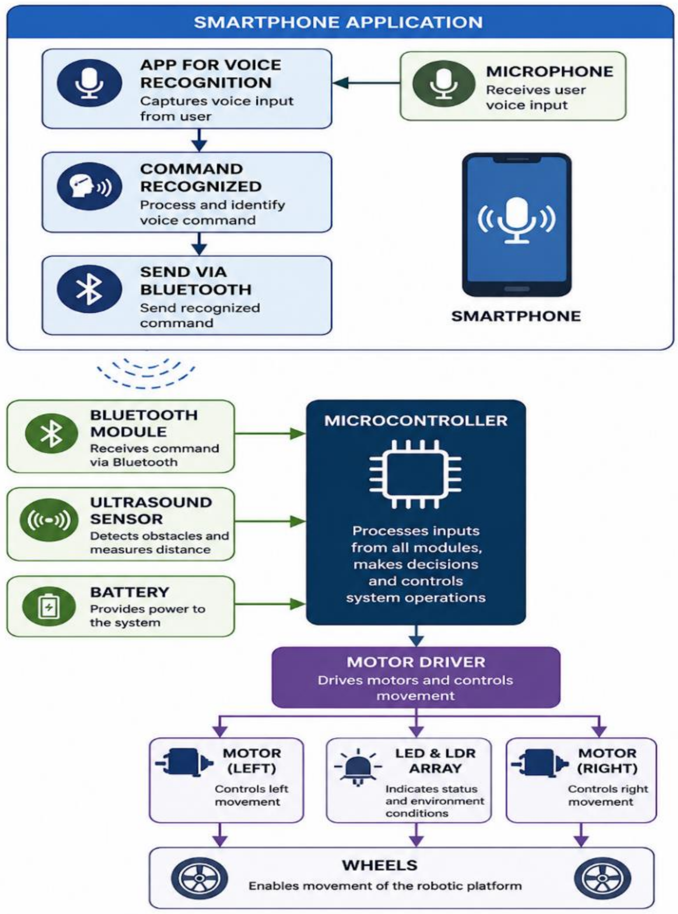

Fig 1: System Architecture of NeuroStride-X for Intelligent Balance Recovery and Mobility Assistance

The system architecture of NeuroStride-X illustrates the interaction between the smartphone application, communication modules, sensing units, processing controller, and mobility subsystem. The process begins with voice input captured through a microphone and processed by a voice recognition application on the smartphone. The recognized command is transmitted wirelessly through the Bluetooth module to the microcontroller. Simultaneously, the ultrasonic sensor continuously monitors the surrounding environment and detects obstacles to ensure safe navigation. The battery supplies the required power for all hardware components and maintains uninterrupted operation. The microcontroller acts as the central processing unit, receiving commands and sensor information, analyzing the data, and generating appropriate control signals. These signals are forwarded to the motor driver, which regulates the operation of the drive motors. The motors control wheel movement, enabling directional navigation and mobility assistance. The LED and LDR array provides environmental status indication and supports system monitoring. This integrated architecture ensures intelligent control, obstacle awareness, reliable communication, and safe robotic assistance for rehabilitation and mobility support.

VII. Experimental Setup

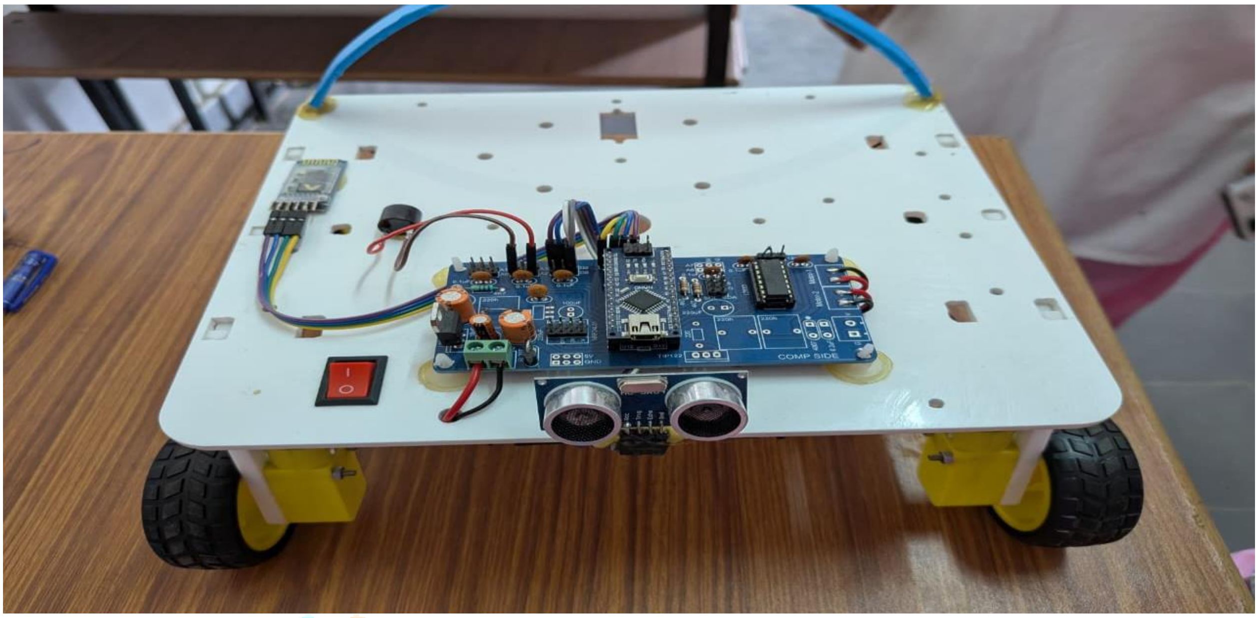

Fig. 2: Prototype Implementation of NeuroStride-X Mobile Robotic Assistance Platform

The prototype integrates a microcontroller, Bluetooth module, ultrasonic sensor, motor driver, and wheeled mobile base to support intelligent robotic navigation and assistance functions.

VIII. Conclusion and Future Works

In this research, NeuroStride-X was developed as an adaptive human-robot platform for balance recovery and mobility assistance. The system integrated intelligent sensing, wireless communication, obstacle detection, and robotic movement control to support individuals with balance impairments during rehabilitation activities. By combining mobility assistance and balance training, the proposed approach enhanced safety, reduced fall risks, and encouraged independent movement. The architecture demonstrated reliable operation through coordinated interaction between sensors, controllers, and actuators. Future work will focus on integrating advanced sensors, artificial intelligence, and real-time motion prediction algorithms for improved adaptability. Additional developments may include wearable monitoring, cloud-based rehabilitation, telehealth connectivity, personalized training programs, enhanced user interfaces, clinical validation, larger scale testing, improved navigation, greater autonomy, energy-efficient operation, and broader healthcare adoption.

References

[1] A. Loro et al., "Balance Rehabilitation through Robot-Assisted Gait Training in Post-Stroke Patients: A Systematic Review and Meta-Analysis," *Brain Sciences*, vol. 13, no. 1, 2023.
[2] F. Baronchelli et al., "The Effect of Robotic Assisted Gait Training With Lokomat on Balance Control After Stroke," *Frontiers in Neurology*, vol. 12, 2021.
[3] Y. Wang et al., "Graceful User Following for Mobile Balance Assistive Robot in Daily Activities Assistance," *IFAC-PapersOnLine*, vol. 56, no. 2, 2023.
[4] L. Li et al., "Mobile Robotic Balance Assistant (MRBA): A Gait Assistive and Fall Intervention Robot for Daily Living," *Frontiers in Robotics and AI*, vol. 10, 2023.
[5] R. Yli-Ikkelä et al., "Effectiveness of Robot-Assisted Lower Limb Rehabilitation on Balance in People with Stroke," *J. NeuroEngineering and Rehabilitation*, vol. 20, no. 1, 2023.
[6] M. H. Yoon et al., "Effect of the Robot-Assisted Gait Training Frequency on Balance and Gait in Stroke Patients," *Physical Therapy Korea*, vol. 31, no. 4, 2024.
[7] J. H. Lee et al., "How Robot-Assisted Gait Training Affects Gait Ability, Balance, and Functional Recovery After Stroke," *Journal of Stroke Rehabilitation*, vol. 31, no. 2, 2024.
[8] F. Paviotti et al., "Equilivest: A Robotic Vest to Aid in Post-Stroke Dynamic Balance Rehabilitation," *IEEE Access*, vol. 11, 2023.
[9] H. Kim et al., "Identifying Best Fall-Related Balance Factors and Robotic Rehabilitation Strategies for Stroke Survivors," *NeuroRehabilitation*, vol. 54, no. 1, 2024.

[10] J. Wu et al., “Research on a New Rehabilitation Robot for Balance Training and Assessment,” *Biomedical Signal Processing and Control*, vol. 86, 2023.
[11] T. Shirakawa et al., “Comparison of the Use and Training Effects of Two Types of Robot-Assisted Gait Training Systems,” *Rigakuryoho Kagaku*, vol. 39, no. 2, 2024.
[12] M. Behery, M. Trinh, C. Brecher, and G. Lakemeyer, “Assistive Robot Teleoperation Using Behavior Trees,” *IEEE Robotics and Automation Letters*, vol. 8, no. 7, 2023.