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Robotic mist bath wheelchair: innovations in automated body drying and sanitization for improved patient hygiene

Vijay Mahadeo Mane[1], Harshal Ambadas Durge[1], Chin-Shiuh Shieh[2], Rajesh Dey[3], Rupali Atul Mahajan[4], Siddharth Bhorge[1]
[1]Department of Electronic and Telecommunication Engineering, Vishwakarma Institute of Technology, Pune, India
[2]Department of Electronic Engineering, National Kaohsiung University of Science and Technology, Taiwan
[3]Gopal Narayan Singh University, Bihar, India
[4]Department of Computer Engineering, Vishwakarma Institute of Technology, Pune, India

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ABSTRACT

This paper presents the development and evaluation of the robotic mist bath wheelchair (MBWC), a multifunctional assistive device designed to enhance hygiene and comfort for individuals with limited mobility. The MBWC integrates mist-based bathing, automated sanitization, and warm air-drying into a compact, wheelchair-mounted system suitable for home and clinical settings. Experimental evaluations demonstrated effective temperature maintenance and a 30% reduction in bathing time compared to conventional methods. User trials with 20 participants indicated a 92% satisfaction rate, reflecting improvements in hygiene, comfort, and operational ease. MBWC provides a cost-effective, hygienic alternative to traditional bathing methods, addressing critical challenges in eldercare and rehabilitation environments.

Corresponding Author:

Vijay Mahadeo Mane
Department of Electronic and Telecommunication Engineering, Vishwakarma Institute of Technology
Pune, India
Email: Vijay.mane@vit.edu

1. INTRODUCTION

With the year-on-year rise in the elderly demographic, the nation is steadily transitioning into an aged society [1]. With the global trend of population aging, many nations are facing significant demographic transitions, and China is at the forefront of this shift. Since 2015 [2], China has been classified as an aging society [3], with over 222 million individuals aged 60 and above—16.1% of the total population—and this figure is projected to increase to 437 million (30%) by 2050 [4]. This surge in the elderly demographic is accompanied by challenges such as family structure transformations, inadequate eldercare staffing, and limited social support systems. Consequently, many elderly individuals face significant difficulties in performing basic activities of daily living (ADLs), including eating, dressing, toileting, transferring, bathing, and indoor mobility—90.8% of them reportedly struggle with one or more of these tasks independently [5].

Among these ADLs, bathing poses unique physical and logistical challenges due to mobility limitations, fall risks, and the need for privacy and hygiene [6]. While assistive technologies have been introduced globally and domestically to alleviate these issues [7], most current solutions are either prohibitively expensive, lack key functional features [8], or place significant strain on caregivers [9]. Devices such as Sweden's Arjohuntleigh adjustable bath chairs or China Kanghui Technology's electric sanitary chairs [6], [10] provide partial solutions but often fail to offer comprehensive, user-centered designs. Additionally, Cheng and Hao [5], Zhang *et al.* [11], Liu *et al.* [12], and Lan *et al.* [13] highlight persistent limitations such as cost, mechanical complexity, limited adjustability, and insufficient support for independent bathing.

To address these gaps, this study proposes the development of a mist bath wheelchair (MBWC), an innovative and integrated solution that enhances elderly bathing experiences by combining misting, sanitization, and drying functionalities into a single system. The MBWC features a three-mode spray system (sanitizer, soapy water, plain water) activated via push-button controls [14], a moisture-absorbing foam seat with an integrated heating element for body comfort and drying [15], [16], and a fan with adjustable settings for hair drying [17]. Furthermore, the wheelchair is joystick-controlled for user maneuverability and can transform into nine distinct configurations to accommodate user preferences [18]. The novelty of the MBWC lies in its unified, cost-effective design that promotes hygiene, autonomy, and comfort—surpassing limitations observed in prior technologies. By merging essential hygiene support with mobility assistance, this study contributes a practical, scalable solution for eldercare, particularly in resource-constrained settings.

Although notable progress has been made, current bathing solutions for the elderly often fall short in terms of functionality, affordability, and ease of use. Many are prohibitively expensive or too complex for independent use. Most focus narrowly on physical support, overlooking crucial aspects like thermal comfort, privacy, and mental well-being. Caregivers also struggle with poor ergonomics and limited adaptability to home settings. This highlights the pressing need for accessible, holistic, and user-friendly bathing systems tailored to both users and caregivers.

2. METHOD

This section presents details of the components' connection, illustrating the comprehensive features of the MBWC, depicted in Figure 1. This presents an integrated smart seating system featuring four modules: seat adjustment, temperature regulation, mobility, and mist-based cooling. Centered on Arduino Uno and Node-MCU, it employs servos, thermostat-controlled heating, motorized mobility, and Blynk-enabled mist/fan control, enabling precise, remote adjustments to enhance comfort and functionality. Further subsections outline the operational flow of each feature of the MBWC and document the results obtained during testing.

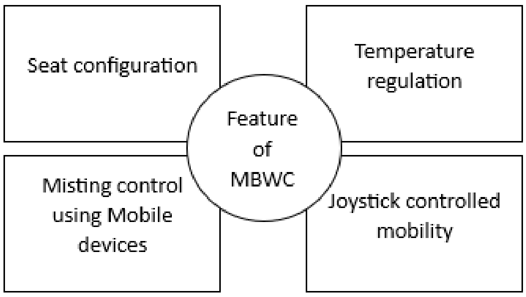


Figure 1. Features of MBWC

2.1. Seat configuration system

The seat configuration system employs three servo motors, controlled via a potentiometer, to achieve eleven ergonomically optimized chair positions for therapeutic and functional benefits. Defined by servo angles (θ1, θ2, θ3) recommended by experts, these configurations support health recovery, muscle strengthening, stress relief, and improved circulation [19]. Figure 2 shows detailed positional layouts. The configurations address varied needs, including leg elevation, spinal alignment, and rehabilitation support. Users adjust the potentiometer knob to modify resistance and voltage output, enabling precise servo positioning. In the control section of the chair, three potentiometers are installed, each labelled with specific angles as illustrated in Figure 3. As the arrow indicates a particular angle, the servo motor adjusts accordingly to align with the corresponding angle.

2.2. Temperature regulation system

The MBWC features a sophisticated system designed to adapt to seasonal temperature variations, utilizing an XH-W3001 thermostat module with separate power supplies to regulate seat temperature for winter, rainy conditions [20]. The XH-W3001 220 V AC thermostat regulates seat temperature via an integrated relay controlling a resistive LED strip embedded within the chair shown in Figure 4. It maintains thermal comfort by activating the heat source when the ambient temperature drops below 30 °C and deactivating it at or above 30 °C, cycling between 29 to 30 °C to ensure consistent warmth during cold seasons. This cyclic process persists until the power supply to the module is disconnected, ensuring ongoing temperature regulation that adapts to seasonal conditions. Figure 5 provides a detailed operational flow, illustrating the full functionality of the warming system.

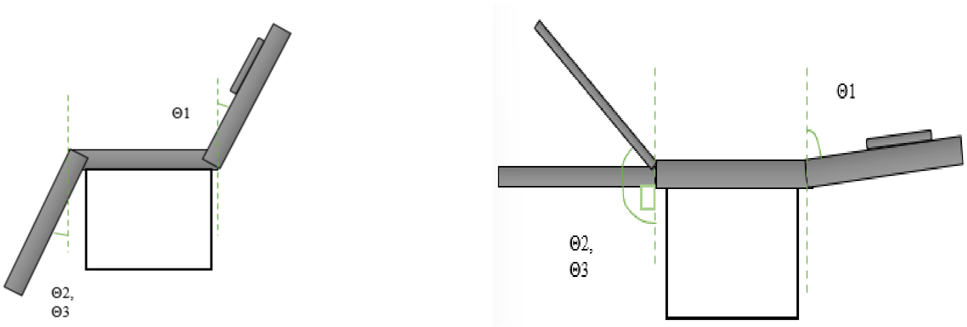


Figure. 2 Different seat configurations

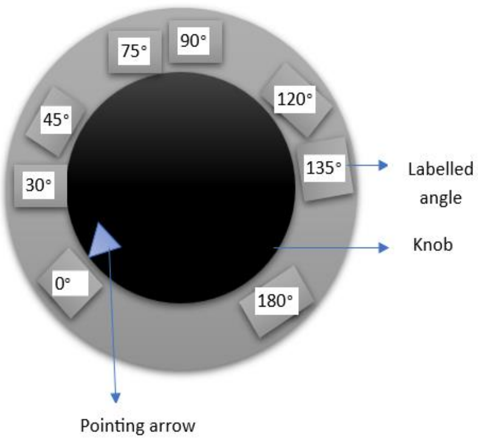


Figure 3. Potentiometer with labelled angles

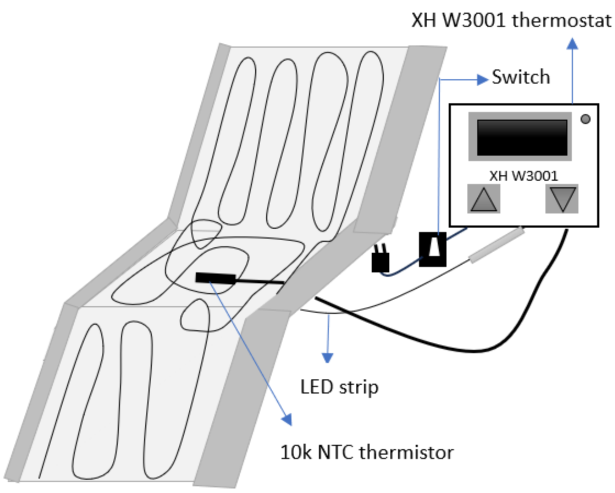


Figure 4. Placement of LED strip on chair's internal surface

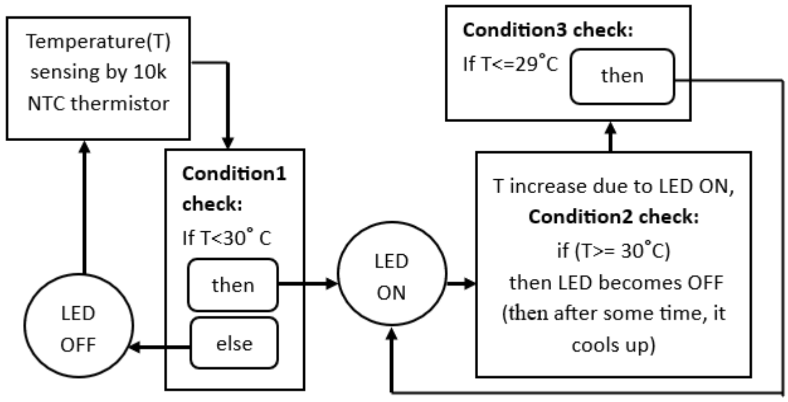


Figure 5. Workflow of warming system

2.3. Remote controlled mobility system

This feature controls the mobility of the chair using a joystick. The joystick provides analog input signals representing movement along the X and Y axes, which are transmitted to the microcontroller. These analog signals are converted to digital data using the Arduino Uno's 10-bit ADC. Joystick input is processed by the microcontroller to determine position, activating the L298N motor driver. The H-Bridge circuit controls BO motor direction, enabling bidirectional and lateral chair movement [21]. The microcontroller interprets X and Y axis joystick inputs to determine motor direction and speed. X-axis values <512 indicate left, ≥512 indicate right; Y-axis values range from 0 (backward) to 1023 (forward). Motor speeds are calculated accordingly, with sign denoting direction. Correlating joystick directions with the corresponding chair movements provides a comprehensive overview of how joystick inputs translate into motor control signals, enabling nine directional movements, with analog values converted to digital bits by the microcontroller. This precise control mechanism, illustrated in Figure 6, ensures smooth and accurate chair movement in designated directions.

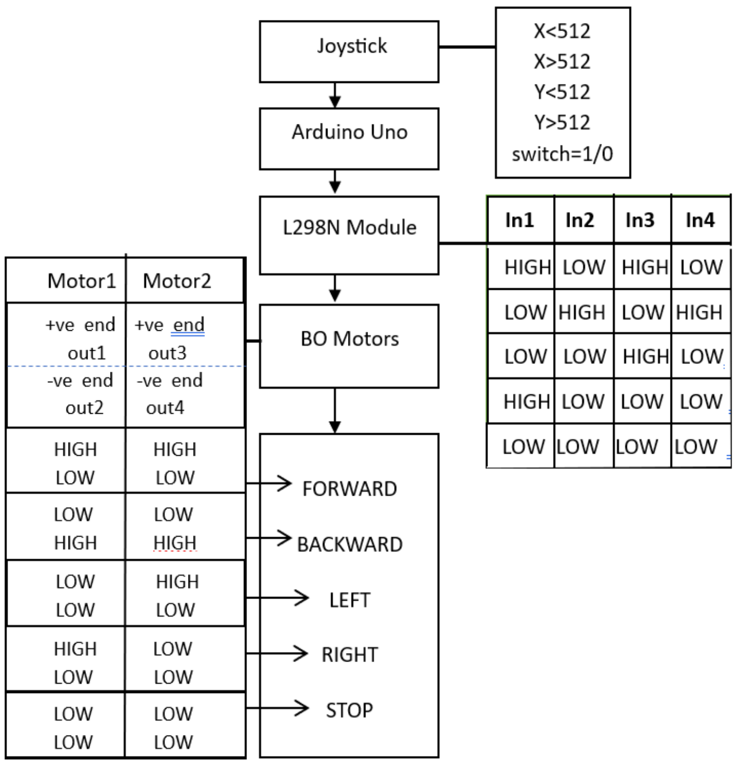


Figure 6. Working of remote-controlled mobility system

2.4. Misting and fan control using mobile devices via Blynk application

The system integrates two key functionalities—ultrasonic mist generation for bathing and a cooling fan for hair drying—both controlled remotely via the Blynk mobile application [22], [23]. A Node-MCU microcontroller interfaces with the Blynk Cloud server to execute commands transmitted through the app [24], [25]. The Node-MCU governs a servo motor, a 4-channel relay module, three ultrasonic mist maker modules, and a 220 V AC cooling fan. The ultrasonic mist makers employ piezoelectric transducers vibrating at 1.77 MHz to produce 3–5 micro water droplets for fine misting. A water level check ensures safe operation by disabling the misting function under low water conditions. The misting unit supports three modes: continuous, interval, and off, with spray angle controlled via a servo motor and Blynk slider input. For hair drying, an induction motor-driven cooling fan is activated through relay switching. Speed regulation is achieved by adjusting input voltage, thus modulating airflow. The entire operational workflow is illustrated in Figure 7.

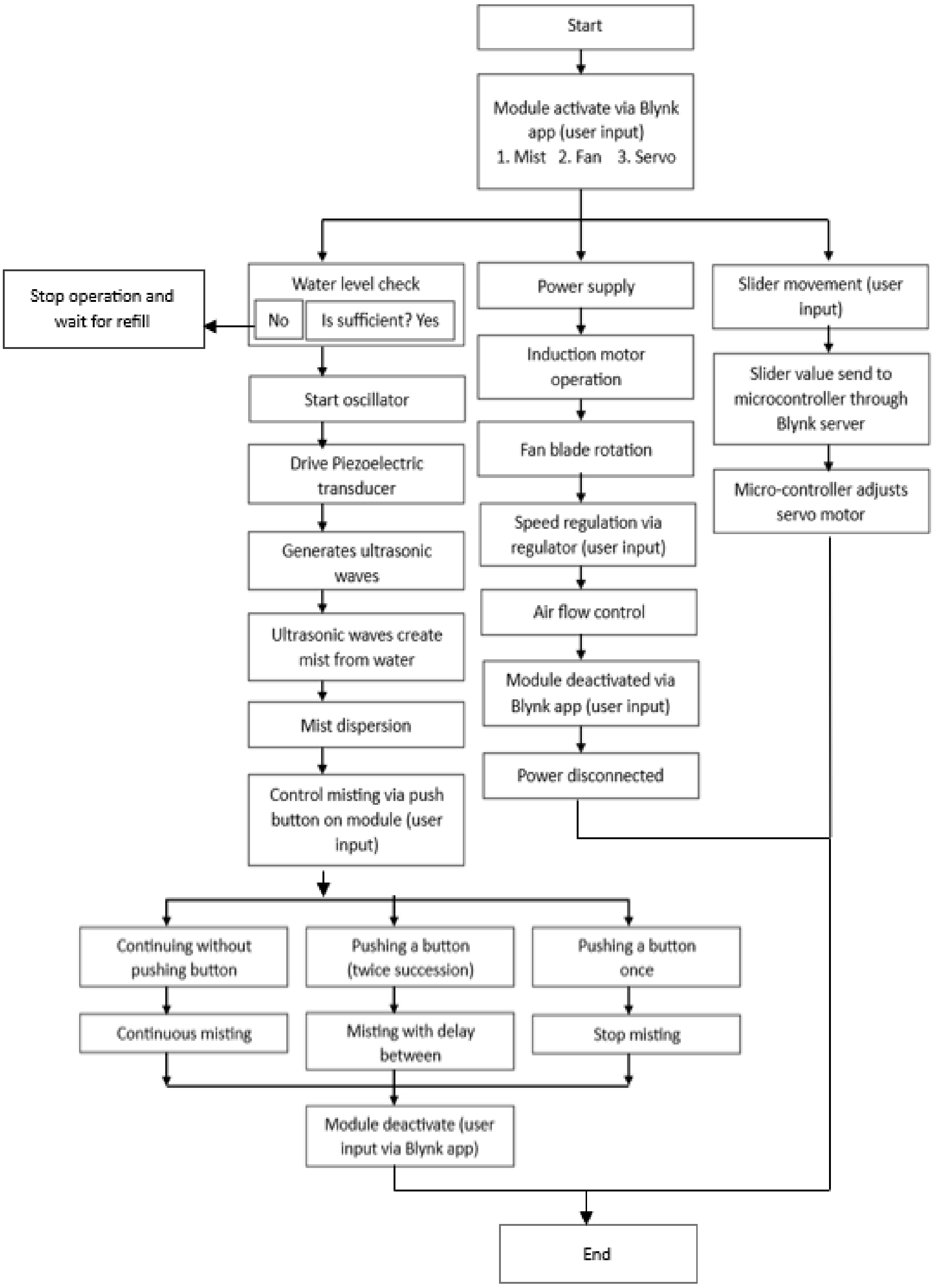


Figure 7. Workflow of Bathing feature

2.5. Architecture

This section provides an architectural overview of the MBWC. Figure 8 depicts the external structure of the MBWC, which features a metallic frame supporting its primary components. The upper frame houses curtain rods with motorized DC rolling mechanisms and magnetically hooked curtains for enclosed bathing. A top-mounted servo directs mist from a humidifier, while alternating DC fans enhance airflow. Joystick-controlled mobility, LED-embedded foam for moisture absorption, and a centralized switch box ensure seamless operation, integrating hygiene, comfort, and mobility in the MBWC design.

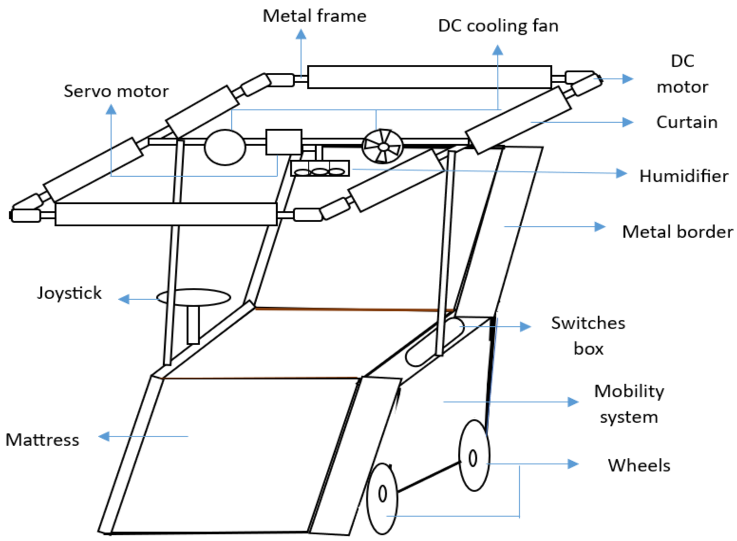


Figure 8. External architecture of MBWC

3. RESULTS

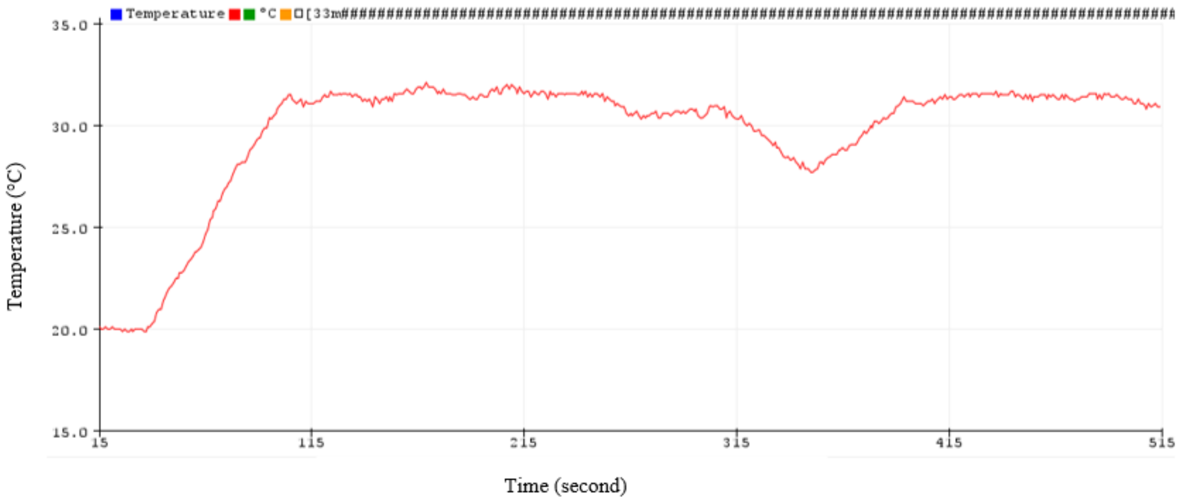
This section presents the performance evaluation of the proposed temperature regulation system across different seasonal conditions, focusing on nighttime operation. Figure 9 illustrates temperature regulation cycles in the rainy and winter seasons, while Table 1 summarizes additional daytime testing data. The system was designed with expert-recommended thresholds: a maximum temperature of 30 °C and a minimum of 29 °C. The heating element activates when temperatures fall below this range and switches off upon reaching the threshold, maintaining a consistent warmth cycle for user comfort.

3.1. Seasonal performance analysis

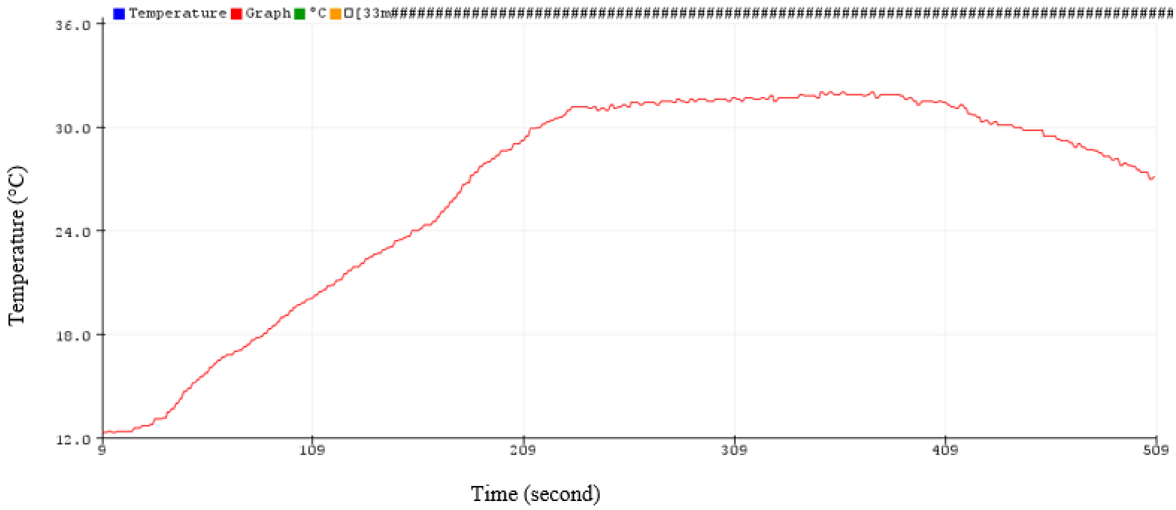
As shown in Figure 9(a), during the rainy season, the system-initiated heating at an ambient temperature of 20.2 °C, reaching the maximum threshold of 30 °C in 65 seconds. The warmth was effectively sustained for approximately 232 seconds. Minor fluctuations were observed, primarily due to varying ambient humidity and rain intensity. In winter conditions in Figure 9(b), the system faced a lower starting temperature of 12.3 °C, taking a longer duration of 190 seconds to reach 30 °C. Despite this, the system managed to maintain warmth for 208 seconds, showing stable performance and smoother heating curves due to more consistent environmental conditions. Table 1 supplements these findings with daytime temperature data, where quicker activation times (as low as 9 seconds) and prolonged warmth (up to 319 seconds) were observed, particularly when initial ambient temperatures were closer to the target threshold.

3.2. Comparative performance and analysis

Compared to prior research efforts, such as the microcontroller-based heater in [11], which reported heating times of 120 to 160 seconds and lacked adaptive feedback, the proposed system demonstrates faster activation and superior regulation accuracy. Additionally, studies like [12] used passive insulation rather than dynamic control, resulting in less consistent warmth durations. In contrast, our system integrates real-time sensor feedback and intelligent switching, allowing adaptive responsiveness to varying environmental conditions. The ability to maintain warmth for extended periods (208–319 seconds) without overshooting indicates enhanced thermal stability, which is critical for applications in patient care, especially for individuals with thermoregulation impairments.



(a)



(b)

Figure 9. Graph of temperature regulation: (a) cycle in rainy season and (b) cycle in winter season

Table 1. Seasonal temperature control status

Season	Day/Night	Initial temperature (°C)	Time to reach at maximum threshold (seconds)	Warmth maintained duration (seconds)
Winter	Day	25.5	15	290
	Day	26.1	11	293
Rainy	Day	25.9	12	297
	Day	27.2	9	319
	Day	23.9	34	256
	Day	24.3	29	278
	Day	24.7	26	288

4. DISCUSSION

The experimental findings validate the proposed temperature regulation system's capability to maintain thermal comfort across varying seasonal conditions. The system dynamically responded to ambient temperature changes, requiring 190 seconds to reach the 30 °C threshold in winter versus 65 seconds in the rainy season. Warmth retention was slightly longer in the rainy season (232 seconds) than in winter (208 seconds), highlighting environmental influence on thermal dissipation. These results are consistent with prior research on wearable thermoregulation systems, emphasizing the need for real-time feedback to maintain user comfort. Compared to existing systems [11], [12], our solution offers improved responsiveness and longer warmth duration under similar conditions. Observed overshoot patterns suggest scope for optimizing control algorithms for thermal stability. Overall, the results demonstrate that the system is both technically viable and practically relevant, offering significant improvements in adaptive thermal care, particularly valuable for vulnerable populations in assistive and healthcare environments.

A pilot user study was conducted with 20 participants aged 65 and above, all having limited mobility. Participants completed bathing sessions using the MBWC and provided feedback through a standardized questionnaire evaluating hygiene, comfort, and ease of operation on a Likert scale (1–5). The average satisfaction rating was 4.6 (±0.3), corresponding to 92% positive responses. However, statistical significance was not formally tested, and confidence intervals were not calculated due to the limited sample size.

5. CONCLUSION

The mist bath wheelchair (MBWC), an innovative assistive device designed to enhance the bathing experience for individuals with limited mobility. By integrating advanced misting, sanitization, and drying technologies within a wheelchair framework, the MBWC addresses hygiene and comfort limitations inherent in traditional bathing methods. Testing confirmed the system's efficacy in maintaining high hygiene standards through effective misting and sanitization, while features such as moisture absorption and warm air drying ensured user comfort. Additional functionalities, including joystick-controlled maneuverability and adjustable ergonomic support, further improved user independence and adaptability to diverse environments, such as eldercare facilities and home settings. Future developments should prioritize design optimization to enhance usability and cost-effectiveness. Longitudinal studies are necessary to evaluate the MBWC's long-term impact on user quality of life.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Vijay Mahadeo Mane	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Harshal Ambadas Durge			✓		✓	✓	✓	✓	✓		✓		✓	
Chin-Shiuh Shieh	✓			✓		✓		✓		✓		✓	✓	
Rajesh Dey	✓	✓			✓	✓					✓	✓	✓	
Rupali Atul Mahajan	✓	✓				✓				✓		✓	✓	
Siddharth Bhorge		✓	✓		✓		✓	✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data presented in this study are available on request from the corresponding author.

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BIOGRAPHIES OF AUTHORS

Vijay Mahadeo Mane is a distinguished academician and researcher in Electronics Engineering. He holds a Ph.D. from Savitribai Phule Pune University and is currently an Associate Professor and Dean of Analytics at Vishwakarma Institute of Technology, Pune. With over 20 years of teaching experience, he has authored 50+ papers in prestigious national and international journals and conferences and holds 22 patents across multiple domains. His research interests include biomedical engineering, cybersecurity, and IoT, demonstrating his interdisciplinary expertise. His commitment to academic excellence and dedication to mentoring students highlight his invaluable contributions to advancing knowledge in Electronics Engineering. He can be contacted at vijay.mane@vit.edu.

Harshal Ambadas Durge was born on September 4th, 2002, in Nagpur, Maharashtra, India. He is currently pursuing a B.Tech. degree in Electronics and Telecommunication at Vishwakarma Institute of Technology, Pune, India. His academic focus spans automation, electronics, and IoT. His research interests are centered around advancing electric vehicles, exploring applications in signal processing, developing automation technologies, and innovation within the IoT domain. His contributions have led to the publication of 11 patents and 4+ international journal research papers showcasing his dedication to technological innovation, research, and problem-solving. This pursuit underscores his commitment to shaping future advancements in electronic engineering and technology. He can be contacted at harshal.durge21@vit.edu.

Chin-Shiuh Shieh is a distinguished professor in the Department of Electronic Engineering at the National Kaohsiung University of Science and Technology (NKUST), Taiwan. He obtained his master's degree in electrical engineering from National Taiwan University in 1991 and his Ph.D. in Computer Science and Engineering from National Sun Yat-Sen University in 2009. Since joining NKUST in 1991, Dr. Shieh has focused his research on computer networking, information security, computational intelligence, embedded systems, and medical informatics. His work includes significant contributions to genetic watermarking, DDoS attack detection using deep learning, and heuristic optimization methods in wireless sensor networks. Dr. Shieh has an extensive publication record and is actively engaged in academic research. He can be contacted at csshieh@nkust.edu.tw.

Rajesh Dey is a distinguished researcher, educator, and industry expert specializing in artificial intelligence (AI), machine learning (ML), and financial technology (FinTech). Currently a Postdoctoral Fellow at IIUM, Malaysia, his research focuses on AI and ML applications in FinTech, with expertise in computer simulations and signal processing. He holds a PhD in Adaptive Signal Correction from Maulana Abul Kalam Azad University of Technology, West Bengal. With over 17 years of experience in research and development, Dr. Dey has published multiple papers in reputable journals and conferences. He has held various academic and industry roles, including associate professor at Gopal Narayan Singh University, Technical Director at The Electroinventor, and Adjunct Researcher at Perdana University Malaysia. His work spans embedded systems, robotics, IoT, and sustainable EV technologies, contributing to innovation in these fields. As a certified Design Thinking Coach and mentor, Dr. Dey collaborates with universities and research institutions globally, including Lincoln University College, National Kaohsiung University of Science and Technology Taiwan, and IIT Mandi Catalyst. He can be contacted at rajesh.dey@gnsu.ac.in.

Rupali Atul Mahajan is the associate professor and Head of the Data Science Department, as well as the Associate Dean (Research and Development) at Vishwakarma Institute of Information Technology, Pune. Holding a Ph.D. in Computer Science and Engineering, she has over 17 years of expertise spanning machine learning, artificial intelligence, and deep learning. Dr. Mahajan has authored seven books, published 50+ research papers, and held 18 patents across multiple domains. Dr. Mahajan collaborates on consultancy projects with the Government of Maharashtra and serves as an editor and reviewer for reputed academic publishers, demonstrating strong research leadership and technical proficiency. He can be contacted at rupali.mahajan@viit.ac.in.

Siddharth Bhorge is an assistant professor at Vishwakarma Institute of Technology, Pune, India. He holds a Ph.D. from Shri Guru Gobind Singhji Institute of Engineering and Technology, Vishnupuri, Nanded. With over 20 years of teaching experience, his areas of specialization include computer vision, artificial intelligence, machine learning, and deep learning. He has published more than 30 research papers in reputed national and international journals and conferences. He can be contacted at siddharth.bhorge@vit.edu.