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User Comfort in Rehabilitation Outreach Centers under Affordable Prosthetic Designs and Damage Accumulation

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Abstract

The provision of affordable prosthetics in low-resource settings represents a critical challenge for global health, particularly concerning long-term user comfort and device durability. This paper investigates the intricate relationship between affordable prosthetic designs, the accumulation of structural damage over time, and the resulting impact on user comfort within the context of rehabilitation outreach centers. By examining the longitudinal degradation of prosthetic materials, specifically focusing on socket wear and alignment shifts, the research elucidates how microscopic and macroscopic damage directly translates to biomechanical discomfort and tissue irritation for the user. Rehabilitation outreach centers serve as the primary nodes for data collection and intervention, providing a unique environment to study real-world prosthetic usage outside controlled clinical settings. Through a comprehensive mixed-methods approach, this study evaluates both the physical degradation of affordable devices and the qualitative experiences of the amputees who rely on them. The findings demonstrate a strong negative correlation between accumulated material fatigue and perceived socket comfort, highlighting the urgent need for iterative design improvements that prioritize not only initial affordability but also sustained structural integrity. Ultimately, this research provides actionable insights for bioengineers and field clinicians, advocating for enhanced material selection and maintenance protocols that can be practically implemented in resource-constrained outreach environments.

Keywords: Affordable Prosthetics; User Comfort; Damage Accumulation; Rehabilitation Outreach; Biomechanics

1. Introduction

1.1 The Global Burden of Limb Loss and Prosthetic Access

The global landscape of physical rehabilitation is characterized by a significant disparity between the demand for prosthetic devices and their accessibility, particularly in developing and resource-constrained regions. According to recent epidemiological estimates, millions of individuals worldwide require prosthetic and orthotic services, yet only a small fraction have access to appropriate and affordable care [1]. This crisis is exacerbated by systemic socioeconomic barriers, inadequate healthcare infrastructure, and the high cost of conventional prosthetic components. In response to this pressing need, numerous non-governmental organizations and academic initiatives have focused on developing affordable prosthetic designs. These devices are intended to democratize mobility, allowing individuals who have undergone amputations due to trauma, vascular disease, or congenital conditions to regain functional independence and participate fully in their communities [2]. However, the pursuit of affordability often necessitates compromises in material selection and manufacturing processes. While high-end prosthetics utilize advanced carbon fiber composites, titanium alloys, and silicone elastomers designed for long-term durability and dynamic response, affordable alternatives frequently rely on low-cost thermoplastics, locally sourced resins, and simplified mechanical joints. This substitution, while economically beneficial and crucial for scaling access, introduces profound challenges related to the lifespan of the device and the sustained comfort of the user. The initial provision of a low-cost prosthetic limb is only the first step in the rehabilitation journey; the true measure of success lies in the long-term utility of the device, which is fundamentally dictated by its ability to withstand the rigors of daily use without causing harm or discomfort to the user [3].

1.2 Defining User Comfort in Affordable Prosthetics

User comfort in the context of lower-limb prosthetics is a multifaceted construct that extends far beyond mere physical fit. It encompasses a complex interplay of biomechanical, physiological, and psychological factors. Biomechanically, comfort is determined by the optimal distribution of forces between the prosthetic socket and the residual limb. The socket, acting as the critical interface, must transmit the weight of the user and the dynamic forces of ambulation without generating localized pressure peaks or excessive shear stresses [4]. Physiologically, the microclimate within the socket, including temperature regulation and moisture management, plays a vital role in preventing skin maceration, blistering, and the breakdown of soft tissue. Furthermore, the overall weight, alignment, and energy return of the prosthetic system influence the metabolic cost of walking, thereby affecting the systemic fatigue experienced by the user [5]. In affordable prosthetic designs, achieving and maintaining this multidimensional comfort is inherently difficult. The use of rigid thermoplastics or standardized, non-customized socket shapes often results in suboptimal load transfer. Moreover, as the residual limb undergoes natural volume fluctuations due to fluid shifts, weight changes, or muscle atrophy, the initial fit of the socket can quickly become obsolete. When user comfort is compromised, the immediate consequences include pain and tissue damage, but the secondary effects are equally devastating. Discomfort is the primary driver of device abandonment, a phenomenon where the user chooses to forsake the prosthetic entirely, leading to a reversion to immobility and a subsequent decline in both physical health and psychological well-being [6]. Therefore, understanding the etiology of discomfort is paramount for improving the efficacy of affordable prosthetic interventions.

1.3 The Role of Rehabilitation Outreach Centers

Rehabilitation outreach centers are essential operational hubs in the decentralized delivery of prosthetic care. Situated predominantly in rural or underserved urban areas, these centers act as the frontline interface between amputees and rehabilitation professionals. Unlike major metropolitan hospitals, outreach centers operate under unique constraints, including limited access to advanced diagnostic equipment, a shortage of specialized prosthetists, and irregular supply chains [7]. Despite these challenges, they are the primary venues where affordable prosthetics are fitted, adjusted, and maintained. Outreach centers also provide a critical vantage point for longitudinal research. Because amputees living in remote areas frequently return to these specific centers for repairs or replacements, the centers offer a natural environment for tracking the life cycle of prosthetic devices under real-world conditions. Researchers and clinicians embedded within these centers can observe firsthand how environmental factors, occupational demands, and varied terrains accelerate the wear and tear of affordable materials [8]. Furthermore, the community-based nature of outreach centers fosters strong relationships between healthcare providers and patients, facilitating the collection of qualitative data regarding the user experience. By situating the study of user comfort and damage accumulation within the context of rehabilitation outreach centers, this research bridges the gap between laboratory-based materials science and field-based clinical realities. It acknowledges that the success of a prosthetic design is not evaluated in a vacuum, but rather in the harsh, unpredictable environments where these devices are ultimately deployed and maintained.

2. Literature Review and Theoretical Background

2.1 Evolution of Affordable Prosthetic Materials and Manufacturing

The historical trajectory of affordable prosthetic design has been characterized by a continuous search for materials that balance cost-effectiveness, ease of fabrication, and adequate structural performance. Early efforts in low-resource settings often relied on repurposed materials, such as PVC pipes, wood, and scrap metal. While these rudimentary devices provided basic mobility, they were typically heavy, difficult to align, and prone to catastrophic failure [9]. The introduction of polypropylene and other moldable thermoplastics revolutionized the field, allowing for the creation of customized, relatively lightweight sockets using simplified vacuum-forming techniques. This approach remains the gold standard in many outreach programs globally. More recently, the advent of additive manufacturing, or 3D printing, has been heralded as a paradigm shift in affordable prosthetics. Fused deposition modeling utilizing polymers like polylactic acid and polyethylene terephthalate glycol enables the decentralized production of highly customized sockets and cosmetic covers. However, despite these technological advancements, the fundamental limitations of low-cost polymers persist. These materials generally exhibit lower tensile strength, reduced impact resistance, and a higher susceptibility to environmental degradation compared to the advanced composites used in high-income settings. Consequently, while the initial barrier to access has been lowered, the operational lifespan of affordable prosthetics is frequently curtailed by rapid material deterioration.

2.2 Mechanisms of Damage Accumulation in Polymeric Prosthetics

Damage accumulation in prosthetic devices is not a single event but a progressive, multifactorial process driven by cyclic loading and environmental exposure. Every step taken by an amputee subjects the prosthetic limb, particularly the socket and the pylon connections, to complex multi-axial stresses. Over thousands of gait cycles, these repeated stresses induce mechanical fatigue within the polymeric structures. Fatigue manifests initially as microscopic crazing or micro-cracks at areas of high stress concentration, such as the trim lines of the socket or the attachment points of the prosthetic foot [10]. As walking continues, these micro-cracks propagate, coalescing into larger fissures that ultimately compromise the structural integrity of the device. Furthermore, affordable thermoplastics are susceptible to viscoelastic creep, a phenomenon where the material permanently deforms under continuous, even low-level, mechanical stress. This is particularly problematic for prosthetic sockets, as creep leads to a gradual loss of the intended anatomical shape, resulting in a loose and unpredictable fit. Environmental factors heavily exacerbate these mechanical degradation pathways. High ambient temperatures, typical in many regions where outreach centers operate, accelerate polymeric creep and reduce the yield strength of the materials. Exposure to ultraviolet radiation from sunlight causes photo-oxidation, leading to embrittlement and a higher propensity for sudden fracture [11]. Additionally, contact with water, sweat, and local soil can cause chemical degradation or abrasive wear on moving joints. Understanding these mechanisms is crucial because damage accumulation operates silently over months, slowly altering the mechanical properties of the device before macroscopic failure occurs.

2.3 The Intersection of Material Degradation and Biomechanical Comfort

The core theoretical proposition of this research is that damage accumulation in affordable prosthetics is directly and intrinsically linked to a decline in user comfort. This relationship is mediated by changes in the biomechanical interface between the device and the user. When a socket undergoes creep and loses its precise shape, the distribution of pressure across the residual limb shifts dramatically. Areas that were designed to bear weight, such as the patellar tendon in below-knee amputations, may lose contact, forcing sensitive, non-weight-bearing tissues to absorb the load [12]. This redistribution generates high pressure gradients and elevated shear forces during ambulation. The human soft tissue response to these altered forces is rapid and deleterious. Increased pressure leads to localized ischemia, where blood flow is restricted, causing deep tissue pain and initiating the formation of pressure ulcers. Elevated shear forces, combined with the heat and moisture trapped within the socket, cause blistering, skin abrasions, and severe chafing. Furthermore, as micro-cracks develop and the overall stiffness of the socket decreases, the suspension system of the prosthetic becomes compromised. A less rigid socket allows for excessive pistoning, which is the vertical movement of the residual limb within the socket during the swing phase of gait. Pistoning not only exacerbates skin friction but also creates a profound sense of instability and insecurity for the user, requiring them to expend additional muscular effort to control the limb [13]. Thus, the physical degradation of the material manifests directly as a deterioration of both physical and psychological comfort, transforming the prosthetic from a tool of empowerment into a source of chronic pain.

3. Methodology for Assessing Comfort and Damage

3.1 Study Population and Outreach Center Settings

To empirically investigate the relationship between damage accumulation and user comfort, a longitudinal, observational study was designed and executed across a network of rehabilitation outreach centers. These centers, functioning as the primary data collection sites, are located in predominantly rural and peri-urban areas characterized by agricultural economies and uneven terrain, providing a rigorous natural testing ground for affordable prosthetics. The study population comprised individuals with unilateral, trans-tibial amputations who had recently been fitted with standardized, affordable thermoplastic prosthetic limbs fabricated at the outreach centers. Participants were selected based on their willingness to participate in follow-up assessments over a continuous twelve-month period and their reliance on the provided prosthetic as their primary mode of ambulation. Exclusion criteria included individuals with significant comorbidities that severely limited their mobility independent of the prosthetic fit, such as advanced peripheral neuropathy or severe cardiovascular disease, to ensure that reported discomfort was primarily attributable to the prosthetic interface. The resulting cohort represented a diverse cross-section of ages, occupations, and activity levels, reflecting the typical demographic profile encountered in global rehabilitation outreach efforts.

Table 1: Baseline Demographic and Prosthetic Characteristics of the Study Population

Characteristic Parameter	Rural Outreach Center Cohort	Peri-Urban Outreach Center Cohort	Combined Total Population
Number of Participants	145	105	250
Mean Age in Years	42.5	39.8	41.3
Male to Female Ratio	98 to 47	70 to 35	168 to 82
Average Daily Usage in Hours	10.2	8.5	9.5
Primary Material of Socket	Polypropylene Copolymer	Polypropylene Copolymer	Polypropylene Copolymer

3.2 Longitudinal Assessment Framework for Damage Accumulation

The methodology for quantifying structural damage required a systematic, non-destructive approach that could be implemented within the resource constraints of the outreach centers. Assessments were scheduled at baseline, three months, six months, and twelve months post-fitting. The primary metric for macroscopic damage accumulation was the dimensional stability of the prosthetic socket. Using customized, low-cost optical scanning tools adapted for field use, three-dimensional topographical models of the interior socket geometry were captured at each interval. These temporal scans were subsequently overlaid and analyzed to calculate volumetric expansion and localized shape distortion, serving as direct indicators of material creep and structural relaxation. In addition to geometrical analysis, rigorous visual and tactile inspections were conducted by trained local technicians to identify surface-level fatigue indicators. A standardized grading scale was employed to document the presence, length, and density of micro-cracks along critical stress corridors, particularly the distal end and the posterior trim lines. Furthermore, the integrity of the suspension mechanisms, including the wear on straps, liners, and sleeves, was systematically recorded. To account for environmental variables, participants also provided self-reported data regarding their primary terrain of use, frequency of exposure to water or heavy agricultural labor, and general maintenance practices. This comprehensive tracking system allowed for the precise quantification of both the rate and the severity of material degradation over the twelve-month observation period.

3.3 Qualitative and Quantitative Comfort Metrics

Simultaneous to the physical assessment of the prosthetic devices, rigorous data concerning user comfort was collected to establish the correlational framework of the study. Recognizing the multidimensional nature of comfort, the evaluation utilized both validated quantitative scales and structured qualitative interviews. The primary quantitative instrument was a modified version of the Prosthesis Evaluation Questionnaire, specifically adapted for cultural relevance and linguistic comprehension within the target populations served by the outreach centers. This questionnaire required participants to rate various domains of comfort, including perceived socket fit, the incidence and intensity of localized pain, the feeling of stability during dynamic tasks, and overall satisfaction, using a standardized continuous scale [14]. To supplement the self-reported data, clinical evaluations of the residual limb were conducted by the outreach center prosthetists. These evaluations quantified the presence and severity of dermatological issues directly linked to poor socket interface, such as localized erythema, epidermal abrasions, induration, and ulceration. The severity of these clinical signs was documented using a standardized dermatological grading matrix. Finally, semistructured qualitative interviews were conducted at the six-month and twelve-month marks. These interviews provided participants with an open-ended platform to describe their daily experiences, articulate specific pain points, and explain how the changing condition of their prosthetic limb affected their occupational capabilities and social participation. The integration of structural degradation data with these comprehensive comfort metrics forms the analytical core of this research.

4. Analysis of Prosthetic Wear and User Comfort

4.1 Patterns of Structural Degradation and Material Fatigue

The longitudinal data collected across the rehabilitation outreach centers revealed distinct and predictable patterns of damage accumulation within the affordable prosthetic cohort. Contrary to the assumption of uniform wear, the degradation was highly localized and heavily influenced by the biomechanical forces of the gait cycle. Dimensional analysis of the socket geometry indicated that material creep was most pronounced in the anterior-distal and posterior-proximal regions. By the six-month assessment mark, over sixty percent of the monitored sockets exhibited a measurable volumetric expansion exceeding acceptable clinical tolerances, leading to a loosening of the suspension and an alteration of the intended weight-bearing profile. Furthermore, the visual inspection data highlighted the insidious nature of fatigue cracking. The onset of micro-cracks was frequently observed as early as three months in highly active users, predominantly initiating at the sharp radii of the trim lines where stress concentrations are maximized. As the study progressed to the twelve-month endpoint, a significant portion of these micro-cracks had propagated into macroscopic structural fissures, necessitating immediate clinical intervention or total socket replacement to prevent catastrophic failure. The rate of this degradation was demonstrably accelerated in participants engaged in agrarian occupations, suggesting that the combination of high cyclic loading, irregular terrain, and environmental exposure creates a severe operating condition that rapidly overwhelms the durability thresholds of standard low-cost thermoplastics.

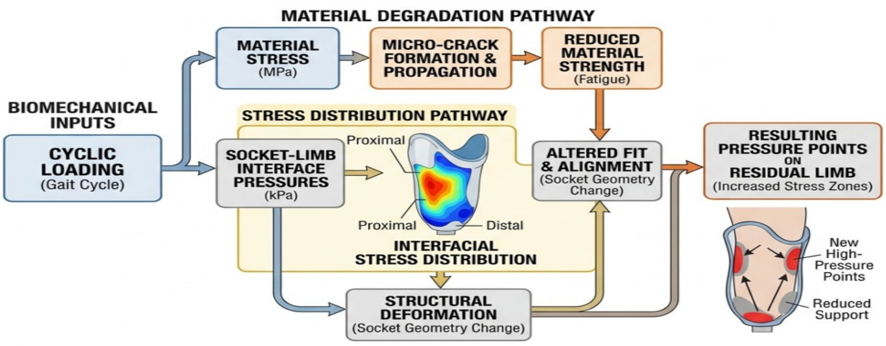

Figure 1: Comprehensive Schematic of Biomechanical Stress Distribution and Material Degradation Pathways in Affordable Lower

4.2 Correlation Between Structural Integrity and Perceived Comfort

The central hypothesis of this study was strongly supported by the statistical analysis of the concurrent datasets, which demonstrated a profound, inverse relationship between the accumulation of physical damage and the user's perception of comfort. At baseline, immediately following the initial fitting and alignment, reported comfort scores were uniformly high, and the incidence of residual limb skin breakdown was negligible. However, as longitudinal material creep altered the internal topography of the sockets, the quantitative comfort metrics exhibited a corresponding, and statistically significant, decline. The data revealed that even minor dimensional distortions, barely visible to the untrained eye, were sufficient to disrupt the pressure distribution network, leading to sharp increases in localized pain scores. The clinical evaluations confirmed this trend, showing a direct chronological correlation between the onset of socket volumetric expansion and the appearance of erythema and abrasions on the sensitive anterior tibial crest and fibular head. Furthermore, the structural degradation associated with fatigue cracking profoundly impacted the perceived stability of the users. As the stiffness of the socket decreased due to fissure propagation, participants reported elevated levels of insecurity and anxiety during ambulation, citing an increase in limb pistoning and a loss of proprioceptive control. This loss of stability required compensatory gait adaptations, which, as detailed in the qualitative interviews, resulted in secondary complications such as premature muscular fatigue and contralateral joint pain.

Table 2: Longitudinal Correlation Matrix of Damage Accumulation Metrics and User Comfort Scores

Assessment Interval	Average Socket Volume Expansion Percentage	Mean Fatigue Crack Length in Millimeters	Average Reported User Comfort Score out of 100
Baseline Evaluation	0.0	0.0	92.5
Three-Month Follow-Up	1.8	2.4	84.1
Six-Month Follow-Up	4.2	8.7	68.3
Twelve-Month Follow-Up	7.9	15.2	45.6

4.3 Impact of Outreach Center Interventions and Iterative Care

The analysis also highlighted the vital, mitigating role played by the rehabilitation outreach centers in managing the consequences of damage accumulation. In instances where users reported early signs of discomfort, outreach technicians were able to intervene utilizing localized heating and reshaping techniques to partially correct the material creep and redistribute pressure away from irritated tissues. Additionally, the application of reinforcing patches over nascent micro-cracks temporarily stabilized the structural integrity of the sockets, extending their functional lifespan. However, the data indicates that these interventions, while crucial for immediate relief, are fundamentally reactive and offer diminishing returns over time. As the underlying thermoplastic material continues to age and experience fatigue, the frequency of required interventions increases, placing a significant logistical burden on both the user, who must repeatedly travel to the center, and the facility, which must allocate limited resources to continuous repairs. The qualitative data strongly underscored this burden, with many participants expressing frustration over the necessity of frequent modifications. This cycle of degradation, discomfort, and temporary repair emphasizes that while localized interventions are indispensable in the current paradigm, they cannot fully compensate for the inherent material limitations of affordable prosthetic designs. A strategic shift towards proactive design improvements is required to fundamentally alter this trajectory [15].

5. Discussion and Conclusion

5.1 Implications for Affordable Prosthetic Design Guidelines

The empirical findings of this study necessitate a critical reevaluation of the design paradigms currently dominating the affordable prosthetics sector. The prevailing emphasis on minimizing initial manufacturing costs has inadvertently created a lifecycle characterized by rapid structural degradation and subsequent user suffering. To achieve sustainable rehabilitation outcomes, design guidelines must evolve to incorporate damage tolerance and long-term dimensional stability as primary constraints, rather than secondary considerations. This requires a transition from homogeneous, low-cost thermoplastics towards hybrid material architectures or localized composite reinforcements in high-stress regions, such as the distal socket base and proximal trim lines. Furthermore, the design of affordable sockets must better account for the viscoelastic nature of the materials employed. By integrating geometric features that distribute stress more evenly and resist creep deformation, engineers can significantly extend the window of biomechanical comfort. The development of adaptable or modular socket systems that can easily accommodate natural volume fluctuations and minor material relaxation without requiring a total refitting process represents a promising avenue for future research and development in this domain.

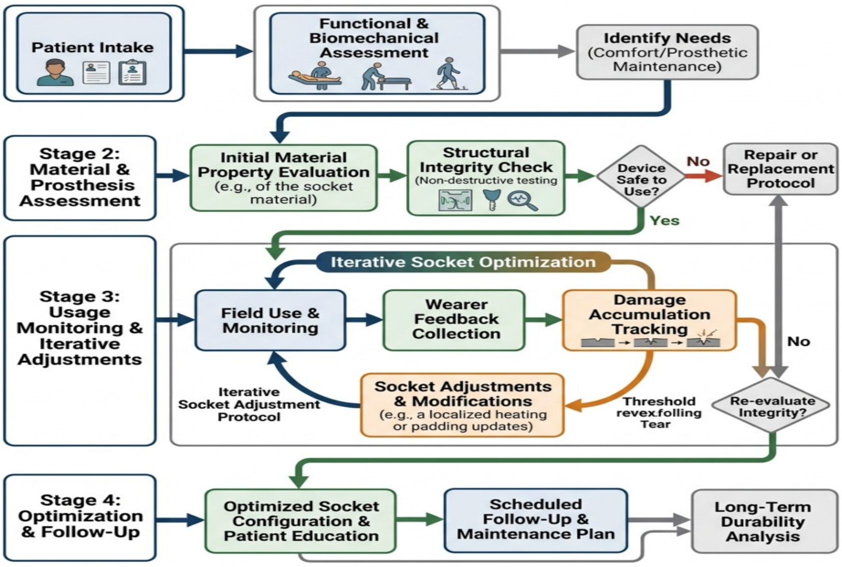

Figure 2: Operational Flowchart of Rehabilitation Outreach Center Interventions for Prosthetic Maintenance and Comfort Optimization

5.2 Enhancing Capacity in Rehabilitation Outreach Centers

Rehabilitation outreach centers are the critical nodes where global health policy intersects with the lived experience of amputees. The data clearly demonstrates that the current model of providing a device and managing its inevitable decline through reactive repairs is inefficient and ultimately detrimental to long-term user comfort. Therefore, strategic investments must be directed towards enhancing the technological and diagnostic capacity of these centers. Equipping field technicians with simplified, digital scanning tools and predictive software models could facilitate the early identification of material creep before it manifests as severe clinical discomfort. Moreover, training programs for local staff should emphasize the biomechanical consequences of material degradation, enabling them to anticipate pain points based on wear patterns and implement proactive modifications. Strengthening the supply chains for slightly higher-grade materials and specialized reinforcement components will empower these centers to provide more durable solutions. Ultimately, transforming outreach centers from basic distribution points into proactive maintenance and research hubs is essential for breaking the cycle of rapid prosthetic failure and ensuring sustained mobility for vulnerable populations.

5.3 Concluding Remarks

This comprehensive investigation has elucidated the profound and often overlooked relationship between the physical degradation of affordable prosthetic designs and the resulting decline in user comfort within rehabilitation outreach settings. By systematically tracking damage accumulation alongside qualitative and quantitative comfort metrics, the research has proven that structural compromises such as material creep and fatigue cracking translate directly into localized pain, tissue damage, and psychological insecurity for the user. While rehabilitation outreach centers provide indispensable services in mitigating these issues, their efforts are currently constrained by the inherent limitations of the materials provided. Achieving true affordability in global rehabilitation requires a paradigm shift away from evaluating cost solely at the point of initial fabrication. Sustainable prosthetic care demands devices that maintain their structural integrity and biomechanical comfort over extended periods of rigorous daily use. By bridging the disciplines of materials science, biomechanics, and global health operations, this study provides a foundational evidence base for developing the next generation of affordable prosthetics, ensuring that efforts to democratize mobility are matched by a commitment to the long-term well-being and dignity of the user.

References

1. Ying, C.; Zhao, Z.; Yi, C.; Shi, Y.; Cai, J. An AoTI-Driven Joint Sampling Frequency and Access Selection Optimization for Industrial Wireless Sensor Networks. IEEE Trans. Veh. Technol. 2023, 72, 12311–12325.

2. Nguyen, T.T.; Oh, H. A Smart Multichannel Slotted Sense Multiple Access Protocol for Industrial Wireless Sensor Networks. IEEE Internet Things J. 2022, 9, 12460–12471.

3. Zhou, W. Research on Wireless Sensor Network Access Control and Load Balancing in the Industrial Digital Twin Scenario. J. Sens. 2022, 2022, 3929958.

4. Sahoo, S.S.; Mohanty, S.; Majhi, B. An efficient three-factor user authentication scheme for industrial wireless sensor network with fog computing. Internet J. Commun. Syst. 2022, 35, e5028.

5. Lessi, C.C.; Gavrielides, A.; Solina, V.; Qiu, R.; Nicoletti, L.; Li, D. 5G and Beyond 5G Technologies Enabling Industry 5.0: Network Applications for Robotics. Procedia Comput. Sci. 2024, 232, 675–687.

6. Wen, Y.; Yang, F.; Song, J.; Han, Z. Optical Wireless Integrated Sensing and Communication Based on Optical Phased Arrays: Performance Metric and Optimal Beamforming. IEEE Trans. Wirel. Commun. 2025, 24, 7221–7236.

7. Yao, J.; Xu, W.; Zhu, G.; Huang, K.; Cui, S. Energy-Efficient Edge Inference in Integrated Sensing, Communication, and Computation Networks. IEEE J. Sel. Areas Commun. 2025, 43, 3580–3595.

8. Banerjee, A.; Costa, B.; Forkan, A.R.M.; Kang, Y.-B.; Marti, F.; McCarthy, C.; Ghaderi, H.; Georgakopoulos, D.; Jayaraman, P.P. 5G enabled smart cities: A real-world evaluation and analysis of 5G using a pilot smart city application. Internet Things 2024, 28, 101326.

9. Zezulka, F.; Marcon, P.; Bradac, Z.; Arm, J.; Benesl, T. Time-Sensitive Networking as the Communication Future of Industry 4.0. IFAC-Pap. 2019, 52, 133–138.

10. He, X.; Lin, F.; Li, M. Codesign of Industrial Wireless Sensor Networks and Consensus-Based Sequential Estimation for Process Industries. IEEE Trans. Ind. Inform. 2023, 19, 8995–9004.

11. Kaur, G.; Chanak, P. An Intelligent Fault Tolerant Data Routing Scheme for Wireless Sensor Network-Assisted Industrial Internet of Things. IEEE Trans. Ind. Inform. 2023, 19, 5543–5553.

12. Roy, P.K.; Bhattacharya, A. SDIWSN: A Software-Defined Networking-Based Authentication Protocol for Real-Time Data Transfer in Industrial Wireless Sensor Networks. IEEE Trans. Netw. Serv. Manag. 2022, 19, 3465–3477.

13. Wang, H.; Zou, Y.; Liu, X.; Li, M. A Fast Convergence Scheme for Distributed Consensus Time Synchronization Using Multihop Virtual Links in Industrial Wireless Sensor Networks. IEEE Sens. J. 2024, 24, 20009–20017.

14. Iqbal, F.; Gohar, M.; Alquhayz, H.; Koh, S.J.; Choi, J.G. Performance evaluation of AMQP over QUIC in the internet-of-thing networks. J. King Saud. Univ. -Comput. Inf. Sci. 2023, 35, 1–9.

15. Aleid, A.; Alhasanat, A. TDoA-Based Decisions Gathering Scheme for Optical Wireless Sensor Networks. IEEE Commun. Lett. 2024, 28, 1472–1476.