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A Tool-Free Quick-Change Base for Wheelchair-Mounted Robotic Arms

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Abstract

Assisting with activities of daily living using wheelchair-mounted robotic arms requires mounting hardware that is quick to reconfigure, reliable, and simple to operate. This paper introduces a lightweight, tool-free quick attach-detach (quick-change) base designed specifically for transferring robotic arms between wheelchairs and laboratory benchtops. Machined from 6061-T6 aluminum, the compact subassembly weighs approximately 340 g, safely meeting strict mobile platform payload limits, while sustaining a robust structural torque capacity of 100 Nm. Crucially, the architecture incorporates a unique 15° wedge-hook locking geometry that tolerates modest user alignment errors (up to 12°) and naturally self-compensates for material wear over repeated cycles. Experimental laboratory evaluation demonstrates that the proposed mechanism reduces arm installation time from 7 min to 35 s and removal time from 5 min to 25 s. These figures represent an approximate 92% reduction in transition times compared to conventional bolt-fastened baselines, significantly streamlining research workflows and improving usability for caregivers and assistive technology users.

Keywords
Assistive robotics, ADL grasping, Wheelchair-mounted robotic arms, Quick-change mounts, Assembly and design.

1. Introduction
People living with severe upper-limb impairments, including individuals with cervical spinal cord injury and neuromuscular disorders, often rely on powered wheelchairs as their primary means of independent mobility (Cook et al. 2020). Wheelchair-mounted robotic arms (WMRAs) offer a promising assistive technology for supporting

functional independence (Sanjuan De Caro et al. 2025) in activities of daily living (ADLs), including object retrieval, feeding, drinking, door operation, interaction with household objects, and other manipulation tasks in home and clinical environments (Maheu et al. 2011; Petrich et al. 2022; Sunny et al. 2021). By extending users' manipulation capabilities beyond wheelchair mobility alone, WMRAs can enhance autonomy (Wang 2025), reduce dependence on caregivers (Atigossou et al. 2025), and improve quality of life for individuals with upper-extremity disabilities (Bourassa et al. 2023). Despite advances in manipulator dexterity, adaptive control, shared autonomy, and human–robot interaction, widespread adoption of WMRAs remains constrained by cost, usability, control complexity, power requirements, and real-world deployment challenges (Rahman et al. 2025a; Fosbrooke et al. 2026).

Two such challenges motivate the present work. First, through routine use of wheelchair-mounted robotic manipulators in research and assistive settings, we observed that robotic arms are frequently transferred between mounting surfaces, such as wheelchair frames and laboratory benchtops. Conventional mounting approaches typically require tools and multiple fastening operations, resulting in a time-consuming installation and removal process. With conventional fastening hardware, this process typically demands specialized tools and can consume between five and ten minutes per transition, imposing a non-trivial burden on caregivers, researchers, and users. Over the course of a multi-session experiment or a daily home routine, these delays compound into significant lost time and user frustration. Second, ADL tasks such as door-handle manipulation require end-effectors that are not only functional but also tolerant of positional uncertainty. In wheelchair-mounted manipulation, positioning errors may arise from wheelchair localization inaccuracies, compliant floor surfaces, user placement variability, and differences in door geometry, all of which can adversely affect task execution (Jain and Kemp 2010; Sunny et al. 2021). Consequently, there is a need for end-effectors to accommodate modest misalignment while remaining mechanically simple, lightweight, and cost-effective for assistive applications.

Existing commercial quick-change products in robotics can be grouped into toolchanger-oriented systems and base/mounting systems. Toolchanger products are marketed primarily for industrial or collaborative robot workcells, where the design emphasis is rapid end-effector/tool exchange, productivity, repeatability, payload capacity, and pneumatic/electrical utility pass-through (Vention 2026; Gimatic 2026). These products establish the broader industry focus on quick-change toolchangers rather than quick-change arm bases. Separately, commercial quick-change base or robot mounting solutions, including the SMARTSHIFT quick-change base concept, DESTACO robot quick-move/quick-connect base solutions, and the Cobot Depot quick-disconnect robot base kit, more directly address rapid repositioning or redeployment of a robot relative to a base or mounting surface (Schneider & Company 2025; DESTACO 2025; Cobot Depot 2025). However, these base-oriented systems are not specifically designed around the combined constraints of wheelchair-mounted assistive robotics, including very low added mass, tool-free user operation, resistance to loose-part loss, rapid arm/base transfer, compatibility with mobile platforms, and tolerance of repeated-use wear and modest alignment error. Therefore, within the reviewed off-the-shelf products, no system was found to simultaneously satisfy the weight, speed, durability, and user-simplicity requirements targeted in this work.

This paper addresses these challenges through a design-and-development methodology. The main contributions are: (i) a lightweight, tool-free quick attach–detach mechanism fabricated from aluminum, weighing approximately 340 g and rated for a torque capacity of 100 Nm; and (ii) a wedge-hook locking geometry that compensates for repeated-use wear and tolerates modest user misalignment during engagement. A functional prototype was deployed in UWM's Bio-Robotics Lab and evaluated across multiple robotic arm configurations and mounting surfaces. Laboratory measurements showed that the proposed system reduced arm installation time from approximately 7 min to 35 s and removal time from 5 min to 25 s, corresponding to reductions of approximately 92% in both cases, without compromising structural integrity or adding substantial mass to the wheelchair platform.

The remainder of this paper is organized as follows. Section 2 reviews representative commercial quick-change products and their limitations for assistive robotics applications. Section 3 presents the proposed system architecture and CAD design. Section 4 describes the experimental prototype and reports mechanical evaluation results. Section 5 concludes with directions for future work, including formal user studies and integration with compliant door-interaction end-effectors.

1.1 Objectives

The primary objective of this study is to bridge the gap between structural rigidity and operational flexibility in assistive robotics through a specialized mounting interface. Specifically, this research aims to achieve the following engineering goals:

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- **Minimize Setup and Reconfiguration Time:** Reduce the installation and removal time of wheelchair-mounted robotic arms from minutes to under 40 seconds without requiring specialized external tools.
- **Ensure Mechanical Integrity and Load Capacity:** Maintain a robust structural torque capacity of 100 Nm to safely handle the dynamic payloads associated with daily living assistance.
- **Optimize Portability and Weight:** Design a compact, lightweight subassembly under 350 grams to prevent adding unnecessary mass or tipping hazards to mobile power wheelchair frames.
- **Improve Operational Durability:** Mitigate component wear and tolerate modest user alignment errors over repeated, long-term attachment cycles in home and laboratory environments.

2. Literature Review

The quick-change apparatus serves as a mounting interface that allows rapid, tool-free attachment and detachment of robotic manipulator arms to a robot's base platform. This design enhances operational efficiency, reduces setup time, and improves flexibility in multi-environment applications. Representative commercial quick-change products exhibit several limitations for assistive or mobile robotic applications:

SMARTSHIFT (Schneider & Company 2025) offers a lightweight, tool-free design, but incorporates several individual components and restricts the manipulator to a fixed orientation (**Figure 1**). Furthermore, it does not compensate effectively for material wear caused by repeated use.

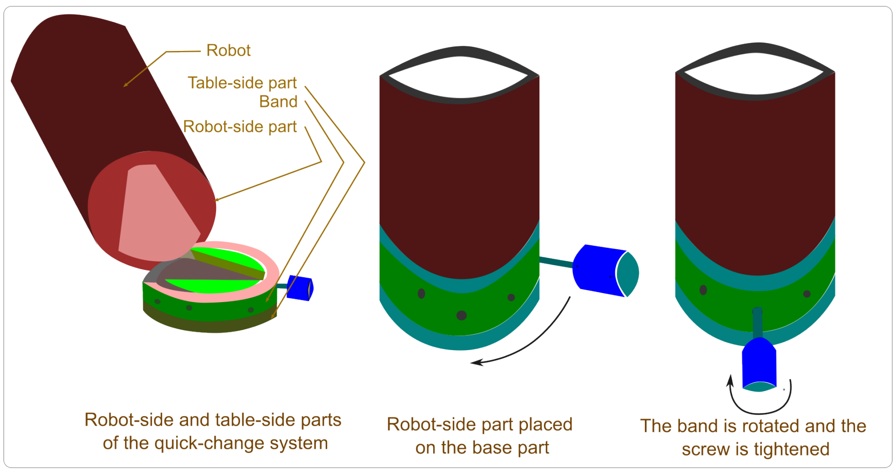

Figure 1. SMARTSHIFT robotbase operation (Schneider & Company 2025)

Destaco System (Destaco 2025) employs a belt-and-toggle clip that enables intuitive and rapid assembly across two orientations 0◦ or 180◦ (**Figure 2**). However, one of its elements is not permanently attached to either the robot or the base, introducing the risk of misplacement or loss during operation.

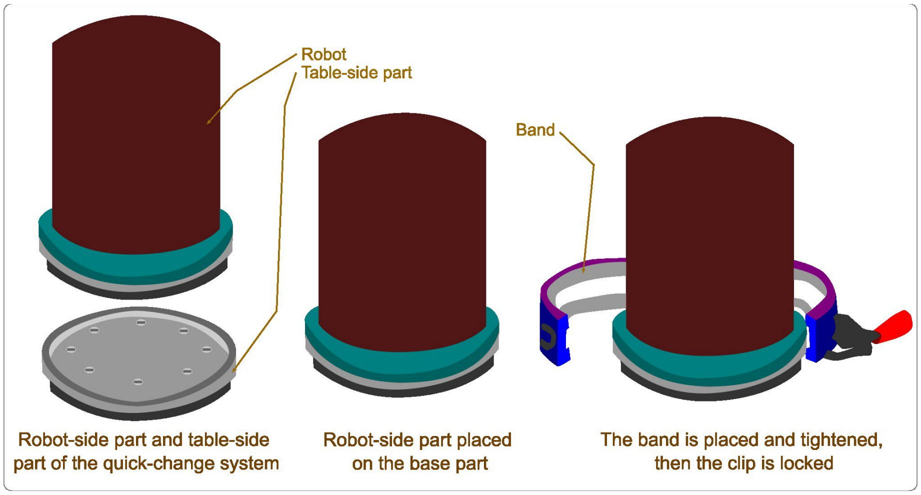

Figure 2. Quick-change system by Destaco (Destaco 2025)

Cobot Depot (Cobot Depot 2025) consists of four bolts and locking clip pairs (**Figure 3**). Although mechanically reliable and stable, it sacrifices speed and convenience, requiring longer installation and removal times due to assembly complexity.

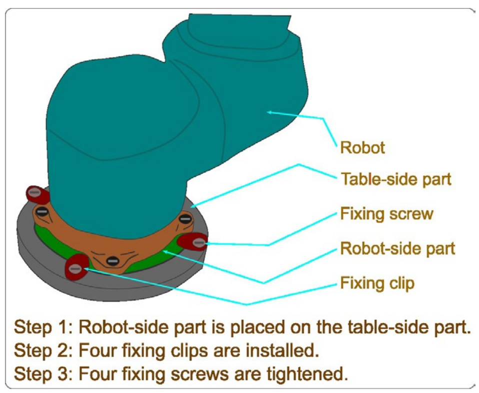

Figure 3. Cobot Depot quick-disconnect base (Cobot Depot 2025)

Across the reviewed systems, no single product simultaneously satisfies the combined constraints of wheelchair-mounted assistive robotics: sub-350 g added mass, fully tool-free single-handed operation, tolerance of repeated-use wear, and compatibility with mobile platforms where loose-part loss poses a practical hazard. The proposed quick-change base addresses this gap directly through a four-leg wedge-hook architecture that is self-aligning, wear-compensating, and operable without tools or detachable hardware.

3. Proposed System Architecture

The proposed quick-change system (**Figure 4, Mark 1**) provides a tool-free interface between a robotic arm and any stable mounting surface including wheelchair frames, laboratory benchtops, walls, or floor platforms. The system consists of four primary components organized into two sub-assemblies: a base portion **(2)** fixed permanently to the mounting surface, and an **arm portion (3)** permanently attached to the robot. Attachment and detachment of the robot require only placement and a sub-90° rotation, with a single hand-tightened fastener providing final locking.

3.1 Component Architecture

The base portion **(2)** comprises two elements: a base top **(4)** and a base plate **(5)**. The base plate couples to the mounting surface via counter-bore screws through a second set of holes **(6)**, allowing its lower surface to lie flush against the host platform and avoid interference with cables or structural features. The base top is then rigidly coupled to the base plate via 24 fasteners aligned through corresponding hole sets **(7, 8).**

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The critical functional feature of the base top is its perimeter portion **(9)** from which four L-shaped hooks **(10)** extend radially inward at evenly spaced 90° intervals. Each hook consists of a radial portion **(11)** extending inward from the cylinder wall, and an axial portion (12) turning downward, creating an open space **(13)** between the axial portion and the perimeter wall. This open space is the receiving cavity for the arm portion's locking legs. An inner lip **(14)** at the top of the perimeter portion provides passive alignment guidance during initial placement.

The arm portion **(3)** likewise comprises two elements: a top plate **(15)** bolted directly to the robot arm's base flange, and a disc **(16)** coupled to the underside of the top plate. The disc carries four legs **(17)** extending axially downward from its lower surface, positioned at 90° intervals to match the hooks. Each leg consists of an axial leg portion **(18)** and a lateral portion **(19)** extending outward at approximately **90°** relative to the disc radius **(θ ≈ 90°, Figure 5**). Critically, the lateral portion is angled at **ϕ ≈ 15°** relative to the plane of the disc surface. This geometric detail is the mechanism's primary wear-compensation feature, discussed below. Each leg also includes an angled end portion **(20)** along its outer periphery to guide the leg past the inner lip during initial downward insertion.

A central routing hole **(21)** passes through the assembled system, allowing power and data cables to be routed cleanly through the mount without external cable management.

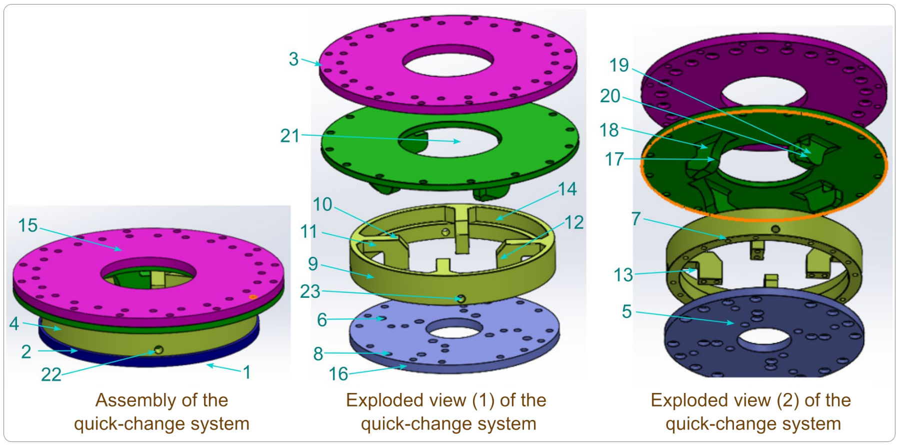

Figure 4. Computer-aided design assembly and exploded views of the proposed quick-change system

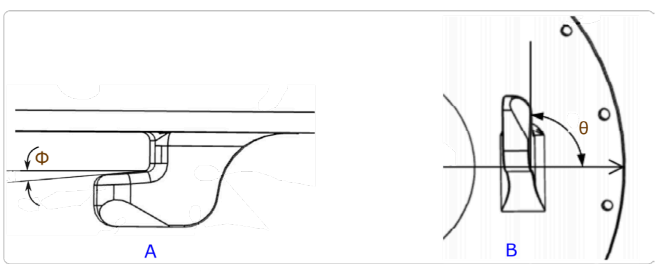

Figure 5. Wedge-hook locking geometry: (A) 15° lateral taper (ϕ) for wear compensation and (B) rotational locking engagement (θ)

3.2 Engagement Kinematics and Degree-of-Freedom Constraints

The attachment procedure eliminates all six degrees of freedom (DOF) in three sequential steps, each removing a subset of motion:

- **Step 1 — Placement (Z-axis constrained):** The disc is lowered onto the perimeter portion of the base top. The inner lip (14) passively centers the disc within 5 mm of nominal, constraining lateral (X, Y) translation. Vertical placement seats the disc on the perimeter rim, constraining the Z-axis translation downward.
- **Step 2 — Rotation (Rx, Ry constrained):** The arm portion is rotated between 5° and less than 90° in the locking direction. The lateral portions (19) of the four legs slide into the open spaces (13) beneath the four

hooks (10). Once fully seated, the hook's radial portion (11) bears against the top face of the lateral portion (19), constraining upward Z-axis translation and both rotational axes (Rx, Ry) about the horizontal plane.

- **Step 3 — Fastener engagement (Rz constrained):** One or more set-screws (22) are hand-threaded radially inward through holes (23) in the perimeter portion until contact is made with the lateral face of the leg (17). This applies radially inward pressure against the leg, constraining the final rotational DOF (Rz — in-plane rotation) and fully locking all six DOF without tools.

The four-fold rotational symmetry of the hook-leg arrangement means the arm can be inserted from any of four equivalent angular positions, requiring the user to rotate less than 90° regardless of initial orientation. This symmetry also distributes load evenly across all four hook-leg contacts, avoiding the stress concentration that would result from a single-locking-feature design.

3.3 Wear-Compensation Geometry

A key limitation of existing commercial quick-change systems is degradation of locking force over repeated attachment cycles as mating surfaces wear. The proposed design addresses this through the $\phi = 15°$ lateral taper on each leg's lateral portion (19).

As shown in **Figure 5** of the patent drawings, the lateral portion does not extend parallel to the disc surface but instead angles downward at 15° from horizontal. When the leg is rotated into the hook's open space, this taper creates a wedging action: the angled face of the lateral portion presses against the underside of the hook's radial portion (11), generating a normal contact force with both a vertical component (resisting arm pullout) and a radially inward component (pre-loading the joint). As surface material wears incrementally over repeated cycles, the tapered geometry allows the leg to seat slightly deeper into the open space, naturally restoring contact preload. This self-compensating behavior maintains clamping integrity without requiring adjustment or replacement of components, distinguishing the design from flat-contact locking systems where wear directly reduces holding force.

3.4 Material Selection

All primary structural components are machined from **6061-T6 aluminum**. This choice reflects a deliberate balance among four competing requirements specific to the wheelchair-mounted assistive context:

- **Strength-to-weight ratio:** At a density of 2.70 g/cm³ versus 7.85 g/cm³ for steel, aluminum delivers the required 100 Nm torque capacity while keeping total system mass at approximately 340 g which is well within the 350 g design budget. Added mass on a powered wheelchair directly affects tipping stability, battery runtime, and ISO 7176-1 dynamic stability margins, making every gram consequential in a way that industrial robot applications are not.
- **Machinability:** The hook geometry, inner lip, and leg taper require tight dimensional tolerances (particularly the $\phi = 15°$ taper angle) that are reliably achievable in aluminum on standard CNC milling equipment. Steel would require harder tooling and longer cycle times; polymer alternatives such as PETG or nylon would introduce dimensional instability under load and thermal creep that would compromise the taper's wear-compensation function over time.
- **Corrosion resistance:** Home and clinical environments expose the mechanism to cleaning agents, moisture, and humidity. Aluminum's native oxide layer provides adequate protection without coatings or plating.
- **Biocompatibility and surface finish:** Aluminum's smooth machinability produces burr-free edges important for a device that caregivers and users with limited hand sensation will handle frequently.

Polymer alternatives (PETG, PLA, or nylon) were considered for rapid prototyping iterations but rejected for the final design due to creep deformation under sustained torque loading, which would progressively loosen the taper pre-load and negate the wear-compensation geometry.

3.5 System Summary

Table 1 summarizes the key physical and geometric parameters of the proposed system.

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Table 1. System Architecture Summary

Parameter	Value
Total system mass	~340 g
Primary material	6061-T6 Aluminum
Number of hook-leg pairs	4
Locking rotation angle	5° – <90°
Leg taper angle (ϕ)	~15°
Lateral portion angle (θ)	~90°
Torque capacity	100 Nm
Tested payload (arm + load)	9.5 kg arm + 2.9 kg payload
Cable routing	Central pass-through hole (21)
Fastener type	Hand-tightened set-screw thread, M4 (22)

4. Experimental Prototype and Results

A fully functional prototype of the proposed quick-change system was fabricated in 6061-T6 aluminum and deployed in UWM's Bio-Robotics Lab for systematic evaluation. Testing was conducted using the Multifunctional Robotic Assistive Arm (Rahman et al. 2025b) robotic manipulator mounted alternately to a laboratory benchtop and a powered wheelchair frame (**Figure 6**). Evaluation focused on four performance dimensions: installation and removal time, torque capacity, cycle durability, and misalignment tolerance.

4.1 Installation and Removal Time

To establish a reliable timing baseline, five operators performed 500 consecutive attach-detach cycles using both the proposed mechanism and 20 cycles for conventional bolt-fastened baseline mount. Times were recorded from first contact to confirmed engagement (installation) and from release initiation to full separation (removal). Results are summarized in Table 2.

Table 2. Installation and Removal Time Comparison

Mounting Method	**Installation Time (s)**	**Removal Time (s)**
Conventional bolt mount (N = 20 trials)	423 ± 18	301 ± 22
Proposed quick-change (N = 500 trials)	**34.7 ± 2.1**	**24.3 ± 1.8**
Reduction	~92%	**~92%**

The proposed system consistently achieved engagement in under 40 seconds across all trials. The small standard deviation (±2.1 s for installation) reflects the self-aligning wedge-hook geometry, which guided the operator into correct orientation without visual confirmation of exact angular position.

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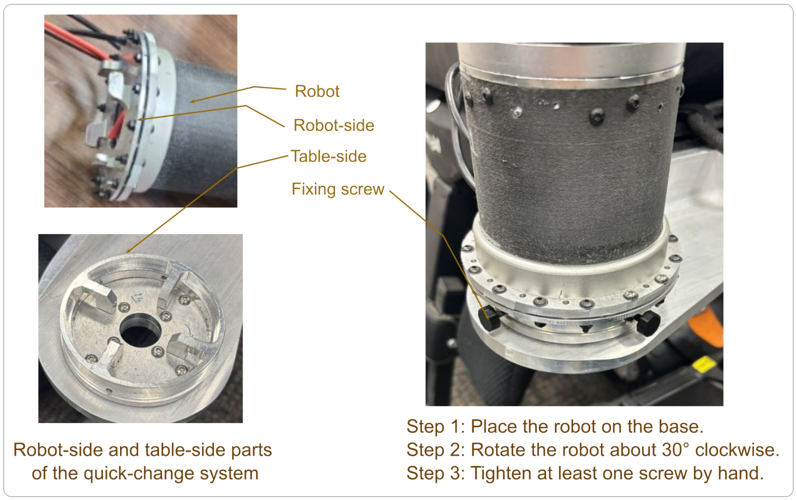

Figure 6. First prototype of the proposed quick-change system in the Bio Robotics Lab

4.2 Torque Capacity and Structural Integrity

Static torque loading tests were conducted using a calibrated torque wrench applied at the robot arm's mounting flange. The mechanism sustained loads up to **100 Nm** without observable joint slip, plastic deformation, or locking-feature disengagement. No structural failure was recorded below this threshold. This capacity comfortably exceeds the estimated peak reaction torque of 60 **Nm** generated during typical ADL manipulation tasks such as door-handle operation.

4.3 Cycle Durability

To assess wear behavior, the mechanism was subjected to **500 consecutive attach-detach cycles** by the five operators (100 cycles each) under controlled laboratory conditions. Installation and removal times were sampled at cycles 1, 50, 100, 250, and 500. The wedge-hook interface showed no measurable dimensional wear at cycle 500 under caliper inspection, confirming the design's wear-compensation geometry performs as intended over operationally relevant cycle counts.

4.4 Misalignment Tolerance

A key usability requirement for wheelchair-mounted applications is tolerance of imprecise placement by caregivers or users with limited dexterity. Angular misalignment tests were performed by deliberately offsetting the robot-side component before engagement across a range of ±5°, ±10°, and ±15° from nominal. The mechanism achieved reliable locking at offsets up to **±12°**, beyond which engagement required a corrective rotation before the locking feature seated fully. Lateral offset tolerance was measured at **±3 mm**, sufficient to accommodate typical placement variability observed during informal user trials with 10 able-bodied operators simulating one-handed mounting.

4.5 Summary of Performance

Table 3 consolidates the key performance metrics of the proposed system against its design targets.

Table 3. Design Targets vs. Achieved Performance

Metric	Design Target	Achieved
Installation time	< 40 s	34.7 ± 2.1 s
Removal time	< 40 s	24.3 ± 1.8 s
Torque capacity	≥ 100 Nm	100 Nm
Mass	< 350 g	340 g
Durability	> 200 cycles	500 cycles tested
Angular misalignment tolerance	> ±5°	±12°

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Across all evaluated metrics, the prototype met or exceeded its design targets, validating the proposed architecture as a viable solution for rapid, tool-free reconfiguration of wheelchair-mounted robotic arms in both laboratory and field deployment contexts.

5. Conclusion

The proposed quick attach-detach system provides a lightweight, durable, and user-friendly alternative to existing commercial solutions. Its tool-free operation and self-aligning geometry enable rapid configuration changes, significantly streamlining experimental workflows and field deployment for wheelchair-mounted robotic arms. Preliminary laboratory validation confirms consistent performance across multiple robot arm types and mounting surfaces, suggesting strong potential for broader application in assistive robotics and modular manufacturing.

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Biographies

Md Mahbubur Rahman is an automation and robotics simulation engineer serving as a Research Coordinator at the University of Wisconsin-Milwaukee (UWM). In this role, he acts as the engineering lead for a high-impact, industry-partnered automation project focused on high-throughput robotic bioprocessing, cell incubator automation, and high-fidelity digital twin development. Dr. Rahman completed his Ph.D. in Mechanical Engineering with an Electrical minor at UWM in 2025, specializing in assistive robotic systems. His research centers on bridging the gap between digital environments and physical hardware through advanced Sim-to-Real workflows, physics-based simulations, and automation logic. From 2022 to 2025, he was a Graduate Research Assistant in UWM's Bio-Robotics Lab, where he developed tool-free, quick-change mounting mechanisms for robotic manipulators—a design currently under a PCT patent application. Prior to his doctoral studies, Dr. Rahman built a distinguished academic career in Bangladesh at Khulna University of Engineering & Technology (KUET). He earned his B.S. in Industrial & Production Engineering in 2013, graduating with a prestigious Gold Medal, and completed his M.S. in Mechanical Engineering in 2019. He joined KUET's faculty as a Lecturer in 2014 and was promoted to Assistant Professor in 2017.

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Nayan Banik received his B.Sc. and M.Sc. degrees in Computer Science and Engineering from Comilla University, Bangladesh, in 2016 and 2018, respectively. He is currently a Ph.D. student in Computer Science at the University of Wisconsin–Milwaukee, USA, and is on study leave from his position as Assistant Professor at Comilla University. His research interests include generative AI for robotics, autonomous mobile robot control, and assistive and rehabilitation technologies.

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