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AnyAdapter: a co-designed smart device support for wheelchair users

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Abstract
For many wheelchair users, the need to operate their chair directly conflicts with using a smartphone for critical tasks like navigation and communication. Existing commercial solutions are often unsuitable, leaving a significant accessibility gap. In this article, we describe how we collaboratively designed a custom accessory to solve this need. Our team consisted of engineers, designers, and a wheelchair user. We engaged in an iterative prototyping process, following clear design principles, and utilizing emergent technologies such as 3D printing and physical computing. The result is the "AnyAdapter," a motorized, open-source accessory that allows a user to mount and precisely position a smartphone with minimal physical effort. Its design combines standardized components with custom-fabricated parts, featuring a robust dual-connection mounting system for stability. We share in this document the co-design process, the final artifact, and key insights from our collaboration. We discuss the importance of balancing digitally fabricated custom parts with commercially available hardware, the tangible benefits of co-design, and the potential future research directions. We contribute a functional AT device and a case study that highlights both the value of co-design and the specific challenges of this approach, such as preventing technology from becoming a "black box" for non-expert participants, in creating empathic and empowering solutions.
Keywords: 3D Printing, Physical Computing, Emergent Technologies, Co-Design, Assistive Technology, Adaptive Devices, User-Centered Design

1 Introduction

People with reduced mobility can increase their autonomy with Assistive Technology (AT) such as wheelchairs [1]. They also benefit, as everyone, from the independence that smartphones can provide when used for tasks like navigation or communication [2]. Nevertheless, the need to control a wheelchair with the hands competes directly with holding a smartphone. Additionally, there is a significant barrier for users with motor impairments that affect both wheelchair control and device handling [3].
One of the co-authors of this paper, Ming Fu, is a disability rights advocate who lives with hemiplegia. He has long iterated with DIY solutions like using zip-ties, tape, and products sold specifically to be installed on bicycles or cars. His

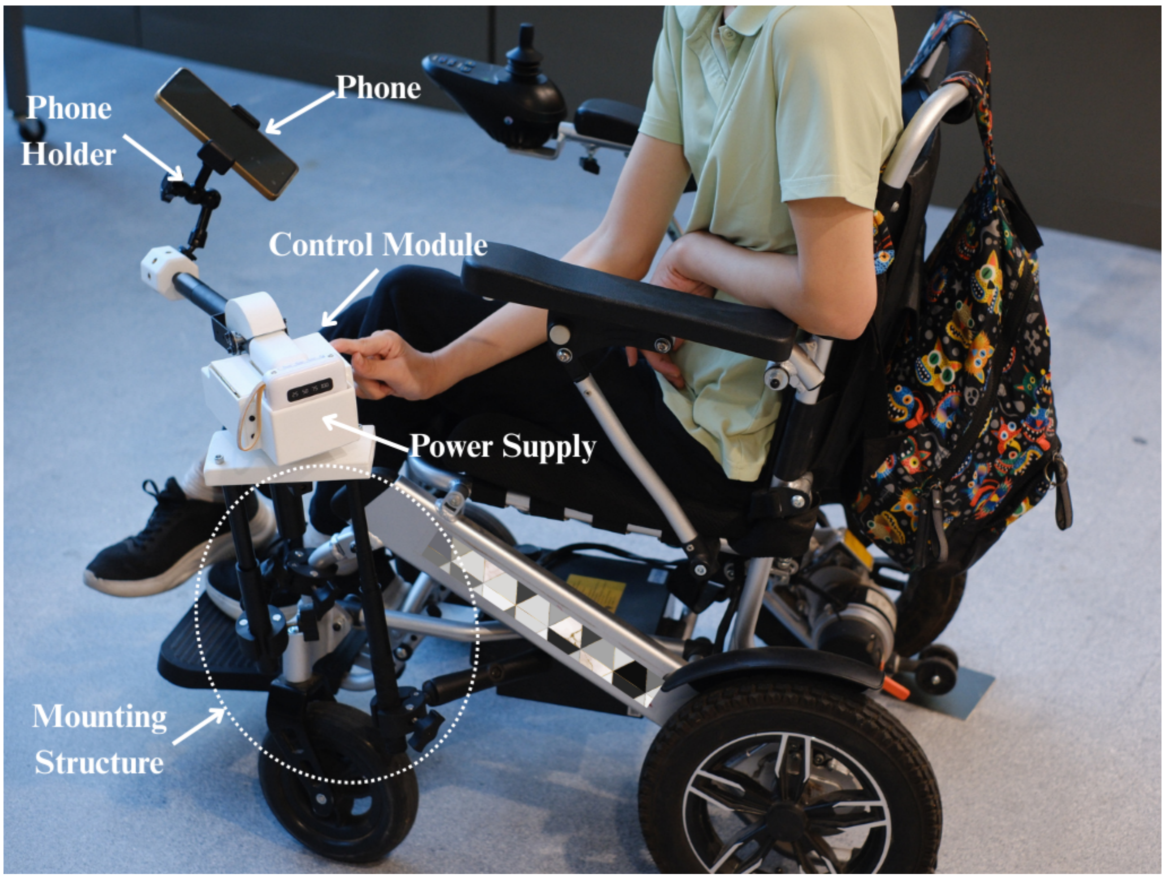

Figure 1. System overview, showing the details of the mounting structure, the power supply, and the control module. The user's phone is mounted on a generic phone holder.

needs as a power wheelchair user are in direct conflict with his use of a smartphone for daily GPS navigation and for social engagement through livestreaming.

Partnering with the other co-authors who have backgrounds in design, electronics, and digital fabrication, we set out to use emergent technologies to collaboratively create a new AT device that would satisfy these unmet needs. We used a participatory co-design process where he acted as a central design partner, and not just a test user [4].

In this article, we review the significant work on using emergent technologies for prototyping in the field of accessibility [5–7], with emphasis on co-design [8]. We describe how we transitioned from user needs, market analysis, and the design framework we decided to use. We guided our collaboration with clear principles while using emerging technologies like 3D printing and physical computing. The result of our collaboration is the "AnyAdapter" we are presenting in this article.

We discuss key lessons about the value of co-design and also reflect on its challenges. Using these technologies can be difficult when participants have different levels of technical expertise, leaving a gap that can be greater when the people co-creating have different physical abilities. We share our experience and the encouraging results we obtained, which required a conscious effort to ensure all co-designers checked in with each other, so that the technology did not become a *"black box"* for any team member. Finally, we discuss the importance of creating adaptable and accessible solutions.

2 Related Work

We provide in this section an overview of prior research showing the importance of the device we set to design, prior use of emergent technologies in the domain of co-creation of AT devices, along with a summary of related design frameworks to collaboratively create and a review of how these prototyping techniques can effectively produce a usable device.

2.1 Smartphone accessories for wheelchairs

The proliferation of mobile computing devices has profoundly altered daily life, yet this digital revolution presents significant challenges for people with mobility impairments [9, 10]. For wheelchair users, the ability to interact with mainstream technologies like smartphones is often limited by upper-body motor impairments or by the physically restrictive frames of their wheelchairs. The standard human-computer interaction (HCI) model, which assumes a user can hold a device and perform fine motor tasks, does not align with the physical realities of many individuals [11].

Historically, the field of AT has sought to bridge this gap with specialized hardware and software [12]. This has included a wide range of devices, from simple items like keyguards and foam grips to complex systems such as alternative pointing devices, switch keyboards, and advanced scanning software [12, 13]. While these tools provide essential access, they are often designed as "one-size-fits-all" solutions, failing to address the highly specific and individualized needs of users [14].

In this context, emergent technologies employing physical computing and 3D printing produce accessible devices that are highly customized. However, there are still very few projects exploring how to use these technologies for wheelchair users holding a smartphone.

2.2 Emergent Technologies are Shifting Design Paradigms

Physical computing is an interdisciplinary field that involves the use of sensors, microcontrollers, and actuators to create physical objects that can process and respond to information from the real world [7]. Simultaneously, 3D printing provides a means for rapid, low-cost fabrication of highly customized, patient-specific devices [5, 15]. This capability moves away from the limitations of mass-produced solutions by making personal-scale fabrication a reality [16, 17].

The intersection of physical computing and 3D printing can be used for personalized AT development. This is a historical shift from the conception that ATs are medical devices focused on normalization and cure [18]. With a new focus on providing users with choices based on personal comfort, fit, and function [14], modern approaches to AT include improving the functional capabilities of an individual with a disability [19]. Under this definition, a well-designed smartphone accessory for a wheelchair is clearly a form of AT, as it provides a service that enables independence and social inclusion.

While the independence and autonomy of disabled users is greatly increased when enabled by the navigation and communication features of smart devices [2], the success of an AT device is not based on function alone. Researchers note that social factors heavily influence whether a person adopts a technology, as AT still now carries a negative social stigma, even if they are technically effective [20]. We share our experience collaborating among the different authors, including people with and without disabilities and the balance we had to keep to achieve full collaboration

2.3 Collaborative Creation of ATs

Human-Centered Design (HCD) employs qualitative techniques like user interviews and usability testing to gain an understanding of user needs and experiences [21]. Nevertheless, HCD often casts disabled users as passive ”test subjects” or sources of empathy rather than active collaborators. The involvement of users is frequently limited to the later stages of the design cycle, such as usability testing. This can result in a ”technology push” rather than a user-led approach, where the solution is pre-defined, and users are simply asked to provide feedback on its implementation [7, 16].
Co-creation is not just a methodology; it is a social and political project that promotes inclusion and challenges ableist assumptions [22]. The traditional design process often implicitly assumes an ”unmarked” generic user persona—a persona that is typically able-bodied—and thus excludes other groups [16, 21].
Instead, Collaborative Design (Co-Design) can be used as a set of iterative techniques and approaches that put users at its heart, working from their perspectives and engaging latent perceptions and emotional responses [22]. In a way, Co-Design could very well be regarded as a new type of DIY adapted to modern times. Combined with physical prototypes led by designers or caregivers, Co-Design becomes a tangible and pragmatic approach that continuously shifts between *‘what is needed?’* and *’what can be built?.’*
If we are to imagine a new generation of ATs, we need Co-Design. Zamenopoulos et al. describe Co-Design as a methodology that empowers individuals, especially those marginalized due to socio-economic, cultural, physical, or mental attributes, to shape their futures by leveraging their unique knowledge and experiences [4]. In our case, using Co-Design was a collaboration framework to work among the co-authors in the project we describe in this article. It required establishing ground rules for co-design applications, and recognizing the benefits of power-sharing in the co-design process [8].

2.4 Reliable and Cost-Effective Prototypes

Prototyping is essential in assistive technology development, as it enables rapid testing and refinement of ideas with users. Digital fabrication tools such as 3D printing and laser cutting now make it possible to produce highly customized solutions at low cost, a practice increasingly adopted in occupational therapy and DIY contexts [15, 23, 24]. Physical computing platforms further extend this capacity by allowing interactive devices to be built and iterated upon quickly [25]. Together, these tools provide a reliable and flexible foundation for co-design processes, where prototypes must adapt to user feedback [22, 26].
Despite the availability of mass-market accessories, economies of scale rarely align with the nuanced needs of people with disabilities [27]. Many users and caregivers already modify commercial products or create ad-hoc solutions to bridge this gap [28]. Following the words of Mark Barlet [29], “Standardize the first 80% and customize the last 20%” we were able to incorporate commercially available parts into our design to achieve a high personalization while keeping the cost down and simplifying the fabrication process of the final prototype. By combining affordable digital fabrication with participatory approaches, it becomes possible to develop prototypes that are not only cost-effective and robust, but also tailored to users’ functional and aesthetic preferences [6, 30]. In our project, this strategy allowed us to create adaptable prototypes that supported daily use while maintaining an open, collaborative process in which design assumptions could be continuously revisited.

3 Methods

3.1 Co-Design Framework

We developed the AnyAdapter using a participatory and iterative co-design process centered on the lived experience of our co-author and co-designer, Ming Fu. Our research team worked in close collaboration with him throughout the project. This approach involved continuous cycles of prototyping and refinement based on his direct feedback, ensuring the design evolved to meet his practical needs.

3.2 Design Requirements

The project began with Fu’s request for a flexible smartphone holder. To understand the market, we reviewed commercially available products in China. Searches for “wheelchair accessories” yielded a low volume of relevant results, and existing products were often simple and low-tech. Our analysis of general-purpose “smartphone supports” confirmed they were unsuitable for wheelchair use due to inconvenient installation, structural mismatches, and impractical positioning. In addition to these market gaps, Fu’s hemiplegia introduced a critical design constraint: the device must be operable with limited hand strength. These findings informed the core design requirements: ease of use, minimal physical effort, modular adaptability, and secure mounting on powered wheelchairs.

Cell 1.1	Cell 1.2	Cell 1.3	Cell 1.4
Cell 2.1	Cell 2.2	Cell 2.3	Cell 2.4
Cell 3.1	Cell 3.2	Cell 3.3	Cell 3.4
Cell 4.1	Cell 4.2	Cell 4.3	Cell 4.4

3.3 Design Principles

When we conceived a collaboration among the co-authors to develop a smartphone support for wheelchair users, we set up a session to define the guidelines that would guide the design. In this session, we decided upon three priorities:

- **Co-Design**, which would ensure that all co-authors were being considered when making design decisions.
- **Modularity and Adaptability**, balancing mass production with personal needs.
- **Economic Accessibility**, using open-source tools and affordable materials to promote replication.

3.4 Iterative Prototyping Process

Our development followed a two-phase iterative process built on our prototyping strategy of combining off-the-shelf (OTS) parts with custom 3D-printed components and Arduino-based electronics. To be able to achieve 20% custom parts, we designed the computer models that we later fabricated using 3D printing. As these parts needed to be structurally strong for parts like adapter bases and mounting interfaces, we used filaments like ABS and Nylon to increase the durability while still keeping a low cost. Being able to design around complex geometries allowed us to accommodate diverse wheelchair frame designs and user preferences. An iterative design–print–test cycle was essential to ensure proper fit, function, and ease of use. We also used rapid prototyping with electromechanical components to motorize the structure and make it interactive. By using open-source projects from the Arduino platform, we were able to try a broad range of compatible components and access an active support community, enabling rapid and cost-effective development.

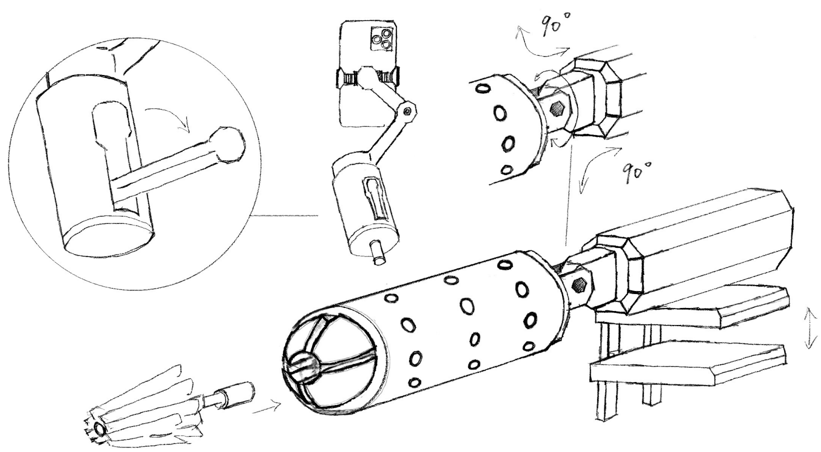

Figure 2. Sketches created during the first phase of our iterative prototyping process. We explored ideas of magnetic attachments, reconfigurable accessories, and servo-assisted levers.

Phase 1: Familiarization and Preliminary Tests. We began with initial design sketches and gathered feedback on a preliminary pilot model. Early testing confirmed a strong need for the device and helped prioritize core functions like stability and ease of phone attachment over minimizing cost.
Phase 2: Iterative Prototyping. Based on the feedback from Phase 1, we identified stability and adaptability as the key challenges to solve in our next iteration. During our second phase, we focused on solving key challenges identified

Product Offered	Description	Advantages	Disadvantage
	• Cost = 16 CNY • Metal Hose, with TPU plastic cover on support arm • ABS Plastic clamp with metal spring	• It supports different kinds of positioning for holding phone • Easy clamp installation • Very low cost	• Vibrations transmit easily along the long suppport arm • Safety concerns for holding phone • Durabiliy and quality concerns
	• Cost = 20 CNY • Plastic body with metal Studs • Two joints combined allow 360 rotation after being installed	• Easy phone attachment • Good security when moving • Easy-adjust to different phone sizes	• Installation inconvenience (needs tools) • Holder body not long enough for wheelchair users
	• Cost = 50 CNY • Aluminum • Universal Joint • Rotate 360	• Easy installation • Universal joint supports different directions • Lightweight	• Holder body not long enough for wheelchair users • Difficult phone attachment • No movement of the support after installation
	• Cost = 200 CNY • Aluminum • One spherical joint allows 360 rotation • A suspension system provides shake-proof support	• Easy phone attachment • Good security when moving • Lightweight • Easy-adjust to different size	• Holder body not long enough for wheelchair users • Medium to high cost

Table 1. Four representative samples of commercially available products online in China, from the most popular e-commerce platform (www.taobao.com).

during testing. For example, the initial single-point clamp was unstable and did not fit all wheelchairs. As seen on Fig. 3, conceptual and technical sketches helped to make the discussions about the best ways the different technologies could be incorporated. Through co-design sessions, we explored different mounting methods and determined that a more stable,

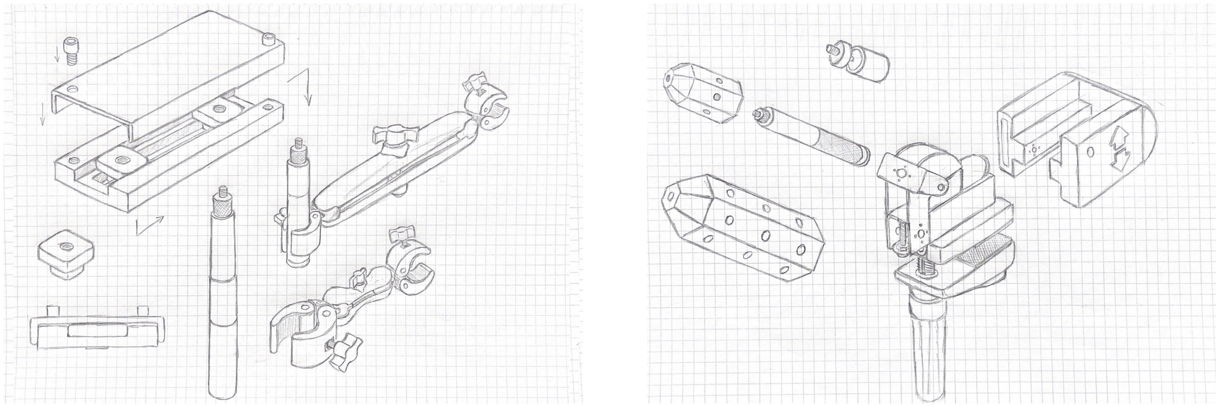

Figure 3. Two initial sketches showing the idea of incorporating commercially available clamps and telescopic rods that are commonly used for photography. These sketches were used during the discussion of the co-designers to decide the installation (left), and the motor placement with the control module (right).

universally applicable solution required connecting to multiple points on the wheelchair frame using adjustable parts.

4 Results: The AnyAdapter Prototype

The final prototype, named AnyAdapter, is a motor-driven accessory for mounting electronic devices onto various wheelchair models. It consists of a main electromechanical body, three interchangeable adapter bases, and two distinct installation methods (a simple clamp and a parallel telescopic rod structure). All components are designed for quick assembly and disassembly.

The final version of “AnyAdapter” is a set of digitally fabricated parts that are seemplesly integrated to commercially available hardware, resulting in a motor-driven phone holder that can adapt to various wheelchair models and smartphones. An example of the final installed device can be seen in the Fig. 1. In Fig.. 4 we can see the different components before being installed. A main body (Fig. 4a), a clamp-based mounting structure (Fig. 4b), a telescopic rod support structure (Fig. 4c), an adapter base (Fig. 4d), two examples of mobile phone holders with gimbals (Fig. 4e and Fig. 4f), and a spare clamp (Fig. 4g).

4.1 System Architecture and Physical Design

We achieved a reliable final device by integrating OTS parts with 3D printed components, following the design principles we explained in the methodology section. With “AnyAdapter” we integrated components of physical computing, including an Arduino microcontroller board, a motor driver, a worm-geared motor, and several custom parts. We were able to drive the adapter base to achieve smooth and precise position adjustment within a 180-degree range. In Figure 5 , we display details of the movement and configurations that can be achieved. We arrived at this specific design by following the co-designing methodology described in the previous section.

User input: The user operates two buttons with ring indicators, which signal to the Control Module contained in the main body. The position is adjusted incrementally by pressing in short pulses or continually. Each button has an illuminated ring for better visibility.

Control Module: The signals generated by the buttons are received by a microcontroller Arduino UNO R3, which is located in the same main body. The software running on the microcontroller parses the input signal and generates the corresponding motor drive command based on the preset control algorithm. The Control Module generates calibrated Pulse Width Modulation (PWM) signals with digital direction signals that will command the motor to rotate clockwise or counterclockwise.

Motor driver: The PWM signals from the Arduino microcontroller are received by the Motor Driver. The motor driver is connected to the Power Supply and the Motor with cables rated AWG 16, so that the current consumption does not interrupt a continuous operation.

Metal Worm-Geared Motor: The motor (model JGY370) was specially selected so that the operation allows for precise control of the phone, but it does not consume power once the motor reaches its desired position. This locking mechanism

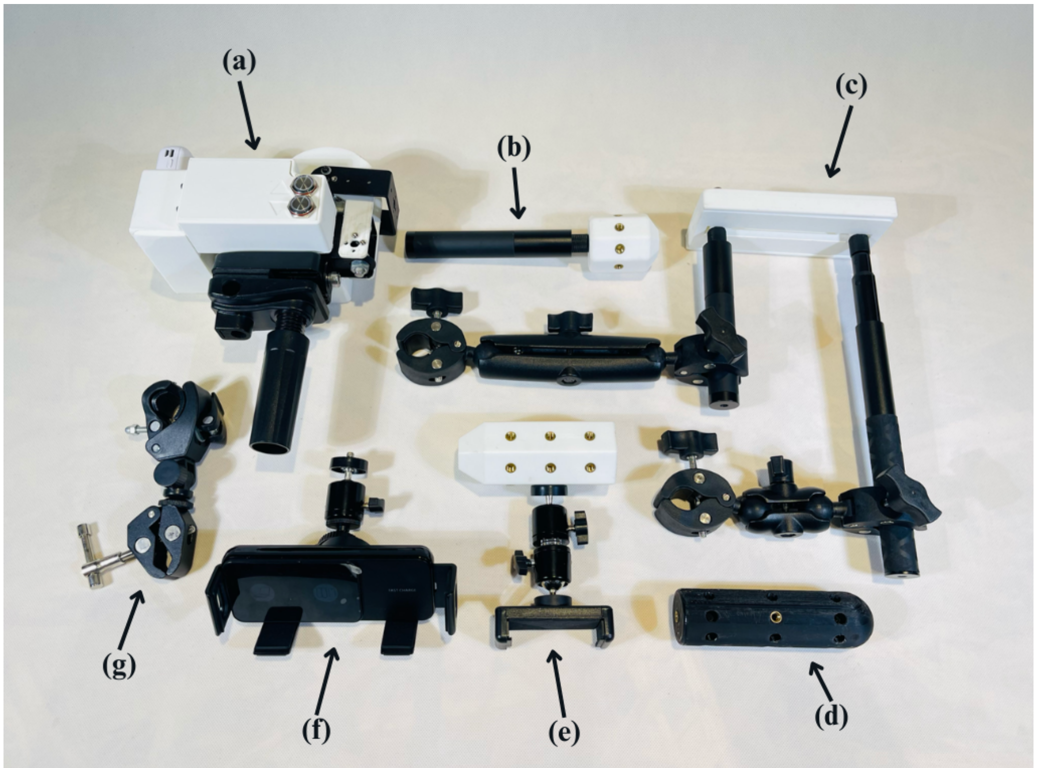

Figure 4. Complete set of parts that compose the final "AnyAdapter" device, comprising.

is possible thanks to the worm-geared reduction (1:3000), which means the motor will move slowly but precisely. The motor rotation angle is limited to within 180 degrees to meet the precise motion range required by the design.

Power supply: The entire system is powered by a 20000mAh, 5V mobile power supply arranged in the main body. The power supply provides working power for the Arduino microcontroller, the metal worm-geared motor, the motor driver, and the button indicator lights. It can also be used as an external power bank to charge external electronic devices (such as mobile phones and tablets) fixed on the adapter base.

Main Body: We designed a case that contains the system control core unit. With a division, it shares space dedicated to integrating system energy modules. A 20000 mAh, 5V mobile power supply is installed to provide a continuous power supply for the entire electromechanical system and support charging of external devices through an integrated USB port. Its internal sandwich structure design achieves line isolation, improving electrical safety and internal regularity.

Adapter Bases: We designed and 3D-printed three adapter bases in different shapes (hexagonal, octagonal, and cylindrical) to improve stability for various device holders. Each base includes a standard 1/4-inch screw insert, making it compatible with most commercial phone and camera mounts.

4.2 Installation Methods

Two methods were developed for mounting the device to a wheelchair. The first is a simple, adjustable clamp for attaching to an armrest. The second is a more robust parallel telescopic rod structure, which uses two clamps to connect to both the armrest support and the front wheel structure. This dual-connection design significantly increases stability, especially when the wheelchair is in motion.

Clamp: The armrest installation method was the first mounting method considered and designed because it is intuitive and simple. After testing various clamps, a clamp designed for desktop phone holders was finally selected. This clamp is adjustable, can be fixed stably, and is modified with sheet metal parts to fit the design of AnyAdapter.

Parallel telescopic rods: As shown in Figure 7, this method consists of two telescopic rods, a long double-end clamp, a short double-end clamp, and a sliding platform. The two double-end clamps with adjustable end directions and angles are installed on the support frame of the armrest and the support structure of its front wheels as the contact parts with

Figure 5. In the left picture, we display a detailed view of the movements and configuration that the "AnyAdapter" is capable of adjusting the extension of the position, rotating along its own axis, attaching most of the phone holders available in the market, and adjusting the angle with an internal motor controlled with push-buttons (left). And in the right picture, we display three different bases that can be interchanged on the system according to the application needed.

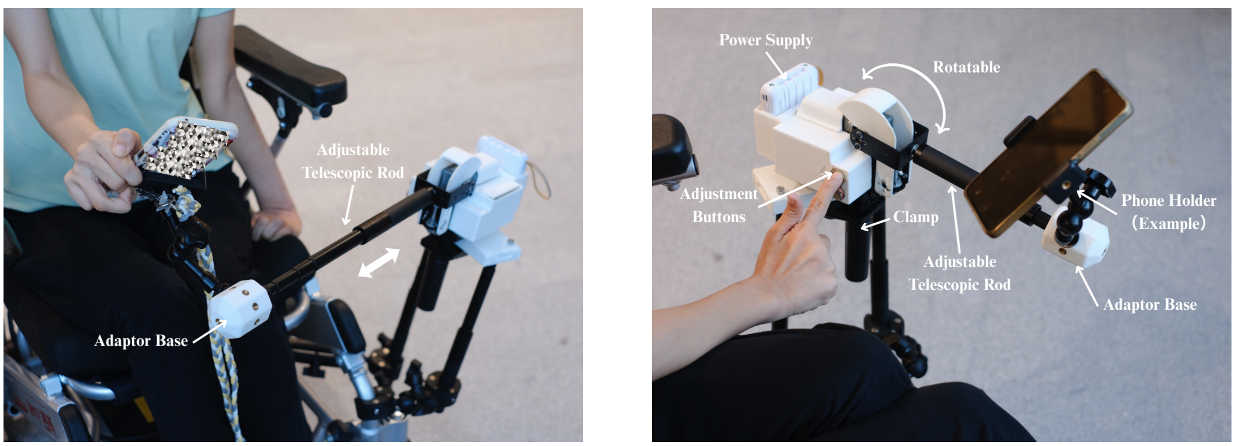

Figure 6. Detail of the Base with the Adjustable Telescopic Rod (left) and the different components that compose the electromechanical design (right). With the adjustment buttons, the user can reposition the smartphone to the desired angle.

the wheelchair. The other ends of the two double-end clamps clamp two telescopic metal rods, which are adjusted to be parallel to each other and perpendicular to the ground. The ends of the metal rods have the same 1/4-inch screws used in other parts of the project. When the metal rods are extended to the same appropriate height, the slide platform is installed on top of them. This small platform is made by 3D printing and has a sliding track inside, which contains two slides with screw inserts. Adjusting the position of the internal slide allows the platform to be stably installed on the top regardless of the distance between the two telescopic rods. AnyAdapter will be installed on the slide platform.

4.3 Co-Designer Feedback on the Final Prototype

We collected the feedback from our co-author and co-designer Ming Fu over the final prototype, where he evaluated our prototype in a real-world use scenario. He installed and used the prototype to hold his smart device to live-stream video, navigate with a GPS application, and have a video call while driving his wheelchair. His feedback focused on three key areas: installation, operation, and the overall design.

As his wheelchair has an atypical frame, installing the parallel telescopic rod structure *"took some trial and error to find the right anchor points."* However, once installed, he was impressed with the stability, commenting that it was *"much more solid than any single-clamp mount I've tried; it doesn't wobble when I'm moving."*

Regarding the controls, Ming Fu confirmed that operating the dual buttons with his elbow was intuitive and did not require

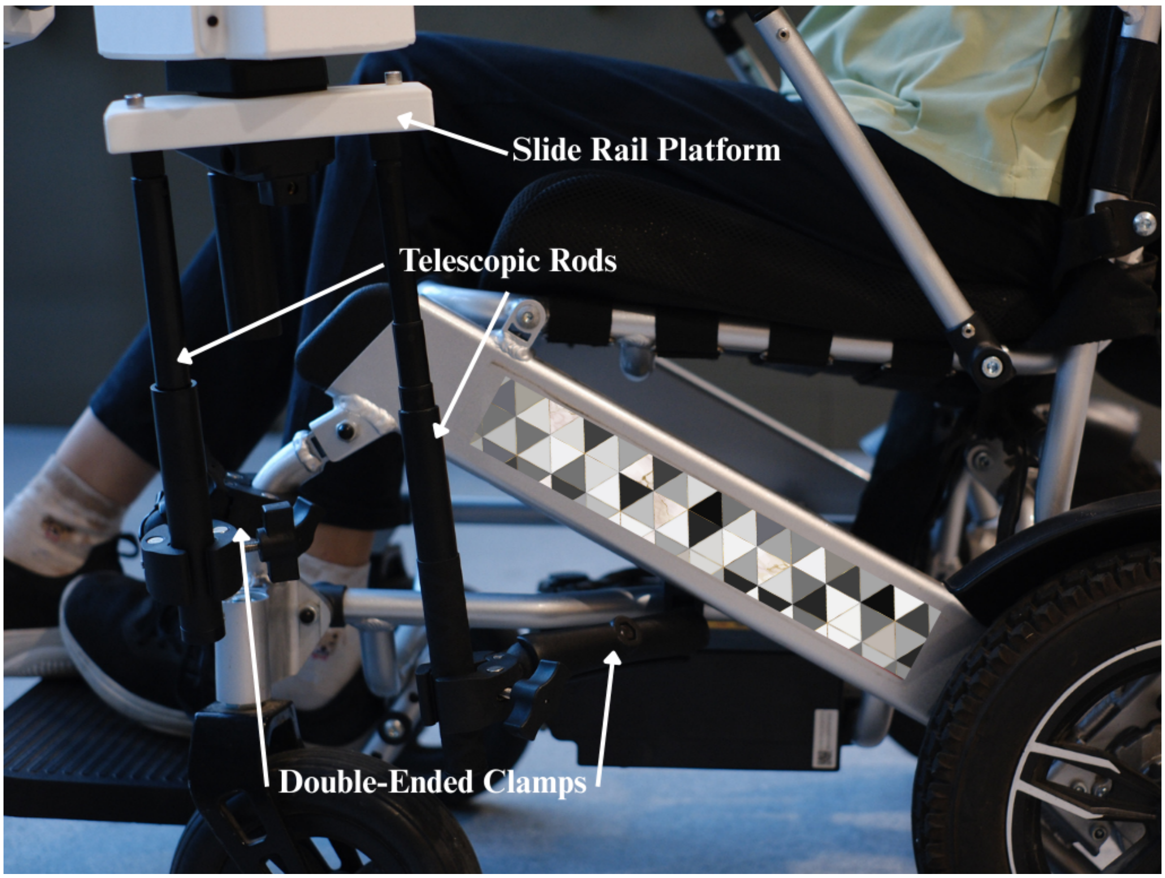

Figure 7. Detailed view showing the Double-Ended Clamps, with their Telescopic Rods and the Slide Rail Platform installed on the wheelchair.

fine motor control. However, he provided crucial constructive feedback, explaining that holding the button down to keep the device in position was difficult. He suggested that a future version should *"lock in place on its own,"* an insight that points toward the need for a self-locking mechanism (e.g., a worm gear) to improve usability.

Finally, he responded positively to the overall design. He appreciated that the standardized 1/4-inch screw mount allowed him to use his preferred phone clamp and remarked that the prototype ”looks like a piece of tech, not a medical device," which he considered a significant advantage for social acceptance.

5 Discussion

Unlocking the industry by using the 80/20 rule: The team decided to use a standard screw size and spacing early on the project, which enabled the team to expand the initial design to use various brackets. This choice not only simplified the manufacturing and assembly process but also significantly increased the flexibility and adaptability of the project. The design concept of ”80% common and 20% customized” proposed by Barlet, Ochsner, and Spöhrer was effectively applied in this project [29]. By prioritizing standardized parts readily available in the domestic market, such as sockets, connectors, and screw holes, the design team was able to quickly replace and test components without compromising functionality. This design strategy brought operational convenience to the different stages of the project and greatly reduced resource investment. In addition, the use of international standard 1/4 screws and pan/tilts made AnyAdapter universally applicable to various brackets or devices. This initial design decision is what ultimately enabled hundreds of choices available in the industry as attachments for the user.

The tangible benefits of co-design: Each stage of the design process highlighted the importance of working with co-designer Fu. Through continuous prototype iteration and feedback, the research team gained a deeper understanding of the needs and constraints of potential users. Zamenopoulos [4] describes co-design as a research method widely used in industry, but the value of this method is particularly evident in this project. Co-designer's feedback not only helped confirm the design direction's correctness but also reminded the team of deviations in certain aspects. For example, when the team deviated from the basic principles of co-design and tried to add complex functions in the early stages of the design, the operability and user experience of the product were affected. By listening to user opinions at each iteration stage, the project team was able to correct biases in time and avoid more time-consuming adjustments in the future.

Future research directions: While prioritizing functional objectives, the initial AnyAdapter prototype became overly bulky and heavy due to its complex structure, extensive components like a high-torque motor, and metal elements. This increased material consumption and imposed an extra burden on users. Similarly, while the dual-button control system was designed for users with limited dexterity, allowing elbow operation, the dual-clamp mounting system requires significant force for installation, often necessitating caregiver assistance. This presents a conflict with the goal of independent use. In next iterations, researchers could focus on simplifying the electromechanical components and exploring new materials. One avenue which could potentially improve this aspect is to design a custom circuit board with other level of technology than simple buttons, allowing people with upper motor disabilities to use gestures or other more complex algorithms to control the movements. Another avenue of exploring at a deeper level the digital fabrication would be to use lightweight, high-strength materials. All these can lead to a more streamlined, low-effort mounting solution that maintains stability without compromising user-friendly accessibility.

6 Conclusion

We presented in this paper the co-design process and development of the "AnyAdapter", a motorized, adaptable accessory that addresses the conflict between wheelchair operation and smartphone use. Our work makes three primary contributions. First, we offer the open-source design for the AnyAdapter, a functional prototype that meets a clearly defined user need. Second, we provide a detailed case study of our participatory process, demonstrating how emergent technologies like 3D printing and physical computing can facilitate the creation of highly personalized solutions. Finally, we share critical insights into the challenges of this approach, highlighting the need for conscious communication to prevent technology from becoming a ”black box” for any co-designer. With this project, we demonstrated that grounding technology development in the lived experience of people with disabilities leads to more effective, empathic, and empowering assistive devices.

Declarations

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval

Not applicable, since one of the co-authors was simultaneously the user testing the device prototypes.

Consent to participate

Not applicable.

Consent for publication

Not applicable

Availability of data and materials

This section is optional. The journal encourages all data used in the analysis to be deposited in available public repositories, presented in the main papers or attached as additional supporting files, in machine-readable format whenever possible.

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