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Improving computer access for individuals with upper limb deficiency through extensionist actions

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Abstract: Despite continuous efforts to promote accessibility, a pressing need remains for increased focus on digital access, particularly for individuals with upper limb mobility limitations, to ensure full integration into computer usage. In response to this challenge, the university extension project Assistive and Adaptive Peripherals (ASAP) was established to leverage 3D printing technology to enhance digital accessibility. This research aimed to construct a conceptual prototype for an assistive mouse and keyboard using readily available and accessible materials, emphasizing the potential for widespread replication. Beyond this immediate goal, the secondary objective was to initiate the extension of the project, focusing on the development of assistive computer peripherals to foster social inclusion. Volunteer participation, including interviews with individuals with limb impairments such as tetraplegia, during the testing phase added a valuable human-centered design (HCD) perspective to the study. This approach ensured that the end-users' needs and preferences were at the core of the design process, making the resulting products more practical and user-friendly. Additionally, a thorough literature review on digital accessibility products was conducted. Through these methodological stages, the research yielded valuable insights, identifying theoretical and technological factors crucial for future applications of the ASAP project. This includes refining the research methodology and advancing the maturity levels of future devices. Looking ahead, the ASAP project will continue its extension activities by developing new assistive peripherals based on the findings of this study.

Keywords: Assistive Technology; 3D Printing; Tetraplegia; Inclusive Design; Computer Peripheral

Melhorando o acesso ao computador para indivíduos com deficiência de membro superior através de ações extensionistas

Resumo: Apesar dos esforços contínuos para promover a acessibilidade, ainda existe a necessidade de maior foco no acesso digital, especialmente para indivíduos com limitações de mobilidade nos membros superiores, a fim de garantir a integração total na utilização do computador. Em resposta a este desafio, foi criado o projeto de extensão universitária *Assistive and Adaptive Peripherals* (ASAP), com o objetivo de utilizar a tecnologia de impressão 3D para melhorar a acessibilidade digital. Esta pesquisa teve como objetivo construir um protótipo conceitual para mouse e teclado assistencial utilizando materiais prontamente disponíveis e acessíveis, enfatizando o potencial de replicação generalizada. Para além deste objetivo imediato, o objetivo secundário é iniciar o projeto de extensão ASAP, centrando-se no desenvolvimento de periféricos informáticos auxiliares para promover a inclusão social. A participação de voluntários, incluindo entrevistas com indivíduos com deficiências nos membros superiores, como tetraplegia, durante a fase de testes adicionou uma valiosa perspectiva de design centrado no ser humano (HCD) ao estudo. A metodologia foi enraizada no HCD, colocando o usuário final no centro do processo de design para o desenvolvimento de produtos e serviços de saúde. Além disso, foi realizada uma revisão da literatura sobre produtos de acessibilidade digital. Através destas etapas, a pesquisa rendeu insights valiosos, identificando fatores teóricos e tecnológicos cruciais para futuras aplicações do projeto ASAP. Olhando para o futuro, o projeto ASAP continuará as suas atividades de extensão através do desenvolvimento de novos periféricos de assistência com base nas conclusões deste estudo.

Palavras-chave: Tecnologia Assistiva; Impressão 3D; Tetraplegia; Design Inclusivo; Periférico De Computador

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Introduction

The Brazilian Law for the Inclusion of People with Disabilities (Statute of the Person with Disabilities) establishes that the fundamental rights and freedoms of people with disabilities are respected, regardless of their physical limitations (Brazilian Federal Law 13,146, July 6, 2015). Disability can affect several aspects of people's quality of life, mainly if no access to assistive technology and rehabilitation programs with specialized professionals exists. Assistive technology can minimize the effects of congenital malformations on cognitive and motor development. However, contemporary society still has many barriers that hinder the full and effective participation of people with disabilities in education, work, and leisure. Such barriers compromise the autonomy, dignity, and well-being of this part of the population. In addition, violating these rights can lead to mental health problems, such as anxiety and depression (Dembo et al., 2018).

The assistive technology area uses technological devices and resources to help people with disabilities in communication, mobility, learning, leisure, and work to promote accessibility, autonomy, independence, inclusion, and confidence for people with disabilities (Moon et al., 2019). Many assistive devices commercially available have low functionality and high cost. For example, upper limb prostheses in Brazil have a high rate of use abandonment due to factors such as excessive weight, standard functionality, loss of motivation to use after a long waiting period for acquisition via the Brazilian Unified Health System (SUS), and lack of an adequate rehabilitation program (Brack & Amalu, 2021).

The Mao3D Program, developed by the Federal University of São Paulo (Unifesp) in Brazil, produces upper limb prostheses in an accessible and efficient way through 3D printing technology (Kunkel et al., 2022; Mao3D, 2023). The Mao3D team uses open-source upper limb prosthetic designs made available by the American e-Nable Foundation, continually improving through a collaborative network of volunteers worldwide. Mao3D Program not only manufactures these prostheses, but also performs the donation and rehabilitation of amputees, children, and adults throughout Brazil, thus promoting broader and more equitable social inclusion (Kunkel et al., 2019; Bina et al., 2020).

The program in focus was created after identifying a social demand for upper limb prostheses for people with malformations or amputations, combined with the availability of 3D models of prostheses shared in open source. The program improves techniques and knowledge related to producing customized prostheses through engagement in research projects. The Mao3D Program expansion has created two extension projects: Ortese3D for upper limb orthoses development and the Assistive and Adaptive Peripherals (ASAP) for digital accessibility devices. These initiatives have broadened the scope of the Mao3D program, catering to various upper limb disorders. Prostheses are provided for individuals with amputations or malformations, orthoses are offered for alignment or restriction needs, and ASAP devices enhance digital accessibility (Fazan et al., 2021).

Due to the Mao3D program's limitation to developing upper limb devices exclusively for amputees requiring prostheses or movement restriction via orthoses, the ASAP project was initiated to cater to an underserved segment of the population: individuals with tetraplegia seeking computer accessibility. This research documents the ASAP project's initial endeavor in constructing a prototype to assist individuals with tetraplegia.

Additive manufacturing, or 3D printing, is a transformative technology that enables the fabrication of physical objects from digital models made from various materials (Gibson et al., 2021). Initially utilized in industrial settings to create optimized and high-quality products, 3D printing has since expanded to other areas, such as healthcare. This expansion opens up exciting possibilities, allowing for the creation of orthoses, prostheses, and assistive devices and promising a future of personalized healthcare solutions (Jin et al., 2015).

Fused Filament Fabrication (FFF) is one of the techniques used in additive manufacturing, which constructs objects by depositing an extruded polymer on a table with vertical movement. In the FFF process, the polymer filament is heated and deposited as fillets, solidifying into layers and ultimately comprising the object's physical structure. In the Brazilian market, several options for low-cost 3D printers and polymeric filaments are available (Gibson et al., 2021). The ascent of emerging technologies has facilitated the dissemination of novel techniques for innovative projects incorporating additive manufacturing and embedded systems.

During the 1980s, the widespread use of microprocessors led to increased process automation through embedded systems that are now ubiquitous in daily human lives. These embedded systems are crucial for the optimal functioning of society. An 'embedded system' is a computer integrated within a more extensive procedure designed to fulfill some of that system's requirements. Numerous embedded system applications exist in healthcare, including automatic insulin pumps for diabetic individuals and biomedical signal interpretation integrated into wheelchairs. These systems are also extensively used in devices such as mice, keyboards, and smartphones, and they are indispensable for digital communication and information access (Gugan, 2020).

Communication is an intrinsic human need that involves transmitting information through symbols and representations. With technological advancements, digital communication has become essential, and access to it depends on devices like computers, tablets, and smartphones. However, individuals with upper limb disabilities may encounter difficulties utilizing these devices to their total capacity. Alternative communication entails using unconventional methods such as hand signals, biomedical signals, eye sensors, and alternative peripherals that allow people with disabilities to access communication. The development of products geared toward individuals with disabilities must consider the human element and prioritize their well-being throughout the design process (Elsahar et al., 2019; Fjeldvang et al., 2023).

Design thinking, a creative problem-solving approach, has helped to solve complex problems by concentrating on a specific user group and has been employed in various sectors, including healthcare and urbanization. Prominent companies have also incorporated design thinking to create innovative products (Brown & Katz, 2009). Optimizing the service provided to patients with disabilities has been an urgent and complex challenge in the health area. Human-centered design (HCD) is a design-thinking approach that places the human factor at the forefront, developing innovative solutions based on patient needs and fostering a sense of empathy toward the users of these solutions (Bohorquez & Montero, 2019). By emphasizing applied participation and actively allowing the volunteer to contribute to the research development, HCD brings forth its humanistic dimension, making the research process less rigid. HCD represents a flexible yet disciplined approach that fosters innovation based on individuals' needs and researchers' experiences (Göttgens & Oertelt-Prigione, 2021).

Methodology

In this research, a prototype of a digital accessibility peripheral that integrates mouse and keyboard functionalities was developed to assist individuals with tetraplegia. Although of only one individual, volunteer participation was invaluable and instrumental in gathering crucial requirements for developing it. The main goal of this study was to create a conceptual prototype using easily obtainable and accessible materials, seeking the possibility of reproduction. The secondary objective is to initiate a project extension focused on developing assistive computer peripherals to promote social inclusion. The methodology upon which this work was based was HCD, emphasizing the empathy phase in its development (Figure 1).

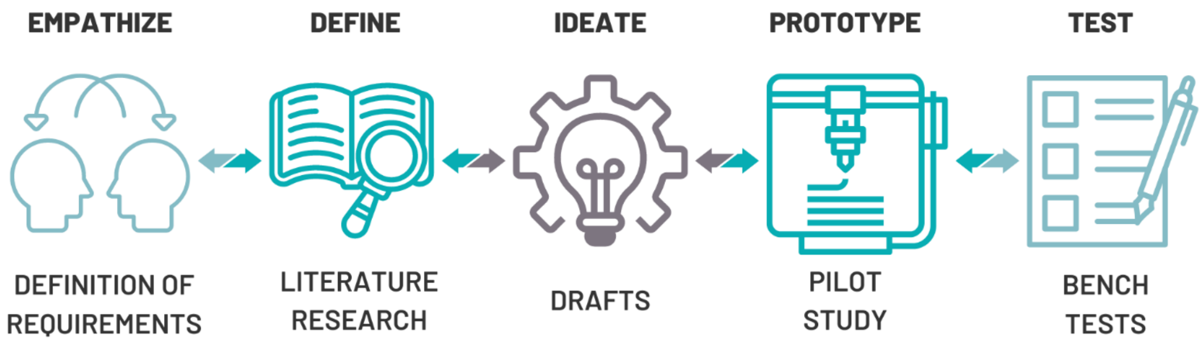

Figure 1. The five methodology steps adopted in this research based on design thinking. Adapted from (Brown & Katz, 2009)

The university extension project related to this research was submitted to the Brazilian Ethics Committee on Human Research and approved under Certificate of Ethical Appreciation number 55016021.0.0000.5505. The device developed in this research was tailored to suit the specific needs of an adult male volunteer with tetraplegia. The 38-year-old volunteer possesses limited upper limb mobility, primarily capable of mobilizing larger muscle groups while lacking precise control over hand and finger movements.

In the initial phase, the empathy stage made understanding the needs, desires, and behavior of the volunteer with upper limb limitations possible. To collect information about their experiences and understand their needs, motivations, and challenges, interviews were conducted online, with each session lasting for 20 minutes. The questions needed to be more structured to understand the volunteer's computer usage and movement limitations.

Definition: Literature research

A comprehensive narrative literature review compared and analyzed the available assistive mice and keyboard features. The objective was to identify the distinguishing factors and gather insights for designing an alternative communication system catering to individuals with upper limb disabilities. In this phase, requirements currently unmet by the literature for assistive technology options for people with upper limb movement impairment were collected. Therefore, commercial and scientific opportunities, adaptations, and available specialized solutions were reviewed to gather requirements for developing a prototype that would stand out among the available options. To carry out the literature review, a search strategy was employed to evaluate the progress of assistive device development in academic research. A specific search query was applied across reputable databases such as Scopus, Web of Science, IEEE Xplore, and ACM Digital Library. The search query comprised the following terms: ("assistive device" OR "assistive technology" OR "assistive peripheral") AND ("upper limb disability" OR "upper extremity disability" OR "upper limb impairment" OR "upper extremity impairment") AND ("personal computer" OR "PC" OR "computer") AND ("mouse" OR "keyboard" OR "input device") regarding a publication period between 2013 and 2023.

Ideation: Drafts

In the ideation phase, initial ideas for developing the digital accessibility peripheral prototype were drafted based on the requirements collected in the empathy and definition phases. The goal was to meet the volunteer's biomechanical requirement of not using fine upper limb movements but utilizing only the user's upper limbs to activate the device controllers.

Prototyping: Pilot study

The prototyping stage of the pilot study involved the technical implementation of the factors defined in the ideation stage, ranging from the physical structure of the prototype to the programming and electronic logic. The prototype's physical body was three-dimensionally modeled using Autodesk Inventor software (Autodesk, USA) and the open-source Blender software (Blender Foundation, USA). This process considered mechanical factors (compression and bending resistance) and biomechanical factors (ergonomic design and the preference to avoid using small muscle groups in its operation). In developing the electronic structure, the electronic materials were prepared and connected to ensure a safe and accurate connection between the joystick modules, controller board, and USB (Universal Serial Bus) cable. This connection enabled the integration of the mechanical part with the software. The movements of the handles are translated into data, which the software interprets and processes. The joystick modules connected to the handles by the adapters facilitate this process. In the software creation stage, the data obtained by the electronic part were collected, processed, and translated for direct use as a mouse and keyboard. The C++ language was used to apply the data interpretation logic on the microcontroller board.

The electronic structure consisted of two ky023 joystick modules connected to an Atmega32u4 microcontroller board and the software written in C++ using the Arduino IDE (Integrated Development Environment). The Atmega32u4 board is a microcontroller board used in electronic projects, commonly employed in developing devices that require a higher processing capacity and user interface. It differs from other boards, such as Arduino Uno, with more advanced architecture and features, such as a high-resolution analog-digital converter, more input and output ports, and native USB support. These characteristics allow the Atmega32u4 board to be used in more complex projects that require greater control and interaction with the external environment.

Acrylonitrile Butadiene Styrene (ABS) and Thermoplastic Polyurethane (TPU) were used to fabricate the first conceptual prototype. The 3D modeling of the prototype was improved for fabrication by the FFF process, using 10% filling in the full-honeycomb style at 235°C for ABS and 230°C for TPU. In the prototyping, ergonomics, mechanical strength, weight, adaptability, and ease of assembly were used. The ABS parts were produced utilizing the FFF process, employing a 20% internal infill following the full-honeycomb pattern. Similarly, the TPU parts were also printed using the FFF method, utilizing a concentric infill pattern that does not favor any particular orientation, thereby promoting even distribution of deformation and movement in the parts.

After the structure was manufactured, the prototype was assembled, and the electronic components (microcontroller and joystick modules) were fixed with wiring and soldering. The microcontroller programming was optimized, aiming for higher input scanning speed and avoiding overheating the controller board. The embedded system programming is the bridge of human-computer interaction, translating navigation habits to the application in the prototype. The commands are stored in arrays, and the analog positions of the joysticks are translated into 64 parts corresponding to the table cells. The code, written in C ++, for implementation in Arduino-compatible boards was developed throughout this study. The essential functions, such as the mouse and keyboard, are implemented but still need optimization and performance enhancement (such as keyboard shortcuts and simultaneous vital combinations).

Figure 2 shows how the operating logic of the assistive peripheral is organized. When each handle is utilized independently, the peripheral operates as a mouse, wherein the left handle triggers mouse command activations, and the proper handle facilitates mouse pointer navigation. However, when the handles are employed simultaneously, considering the eight distinct positions each handle can assume, the combined configuration allows for 64 potential keyboard mode activations, resulting from the various combinations between the eight positions of each handle. The navigation logic was designed to rely solely on the movement of two handles placed equidistant from the center of the 35 cm long prototype to prioritize ergonomic usability and mitigate the risk of injuries. This configuration enables the volunteer to manipulate the handles simultaneously without exerting excessive shoulder effort.

Bench tests

The bench test phase was essential to test the integration between the electronic and mechanical parts of the software. Through this, the requirements and differentials underwent functionality tests and readjustment. The tests were conducted with the volunteer using the digital accessibility peripheral prototype for 10 minutes, simulating daily use, from writing to web browsing. The bench test stage was responsible for perceiving and resolving minor problems that would be undetectable only in the ideation and conception phases. One of the most critical aspects of this prototype is the quality of navigation, which includes accuracy, speed, and adaptability. For the tests in this stage, the prototype was tested before any change to perceive possible improved aspects. Both the electronic system's austerity and the software's functionalities were evaluated. Defining the requirements necessary for improving the prototype through bench tests will allow future research with volunteers, ensuring that the problems in the mechanical part and limitations in the software found during the trials are adequately solved. The requirements will ensure that a volunteer can use the equipment autonomously with increased accuracy of qualitative data.

Keyboard mode (combinations)								
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**
1	e (E)	o (O)	a (A)	m (M)	n (N)	h (H)	l (L)	v (V)
2	r (R)	s (S)	i (I)	u (U)	q (Q)	f (F)	b (B)	ç
3	p (P)	d (D)	y (Y)	c (C)	z(Z)	h (H)	j (J)	g (G)
4	w (W)	x (X)	k (K)	Shift	^(~)	Esc	Win	Caps Lock
5	1 (!)	2 (@)	3 (#)	4 ($)	5 (%)	6 (¨)	7(&)	8(*)
6	.(>)	,(<)	/(?)	-(_)	9 ("(")	0 (")")	" (')	´(`)
7	Tab	Alt	Ctrl	Backspace	=(+)	Fn	/(?)	Fn
8	[{	] }	;:	"	Insert	Fn	MM	Fn
Keyboard mode (individual commands)								
Right handle	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
	←	↑	→	↓	Tab	Enter	Backspace	Space
Left handle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
				MM				
Mouse Mode								
Right handle	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
	Direction	Direction	Direction	Direction	Direction	Direction	Direction	Direction
Left handle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Mouse 1	Mouse 3	Mouse 2	KM	Fn1	Fn2	Fn3	Fn4

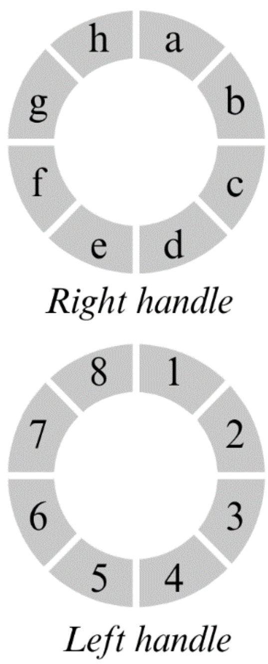

Figure 2. Operating logic of keyboard mode and mouse mode of the assistive peripheral.

Results and Discussion

Empathy: Definition of requirements

The interview with the volunteer revealed that they had difficulties using traditional mouse and keyboard peripherals due to their limited fine motor skills in their hands and arms. He demonstrated greater gross motor coordination in their upper limbs, making using traditional peripherals that require delicate and precise movements challenging. The volunteer also reported accidental button pressing and needing more precision and agility when navigating standard computer peripherals. As a result, the empathy stage helped identify the primary requirements for the conceptual design of the research prototype, which included suitable triggers for gross motor movements, unnecessary use of fine motor movements, large spacing for triggers, and a navigation logic that enables agility and precision.

Definition: Literature research

Five different assistive technology options were analyzed to collect requirements that would serve as a differential for the project development. A flexible set for computer access was proposed for people with difficulty using a conventional keyboard and mouse. Although the device proved efficient in adapting to specific cases, the navigation speed was limited, and the way to use the device needed to be standardized, which required specific training for each user. Shih (2012) developed software that assists people with upper limb disabilities in using keyboards, especially those with cognitive alterations such as severe autism. Although the solution cost was low because it used traditional peripherals, it still required a certain level of fine movement and precise upper limb control, which could be a limiting factor for some people. Another alternative, proposed by Kawala-Janik et al. (2015), used biomedical signals to control video games by interpreting and mapping signals measured by sensors attached to the user's head. This approach offers an alternative for people without upper or lower limb movement. However, although promising, the solution still needs to be more effective for accurate and agile navigation. Cáceres et al. (2018) proposed an assistive solution for users with difficulty using a conventional mouse and keyboard, using eye-tracking technology, which tracks their eye movement relative to a digital pointer. The answer was based on recognizing the user's eye position, connecting with the mouse pointer, and navigating by eye-tracking. Although efficient and valuable, the navigation speed is limited, and the accuracy could be higher, even without requiring upper limb movement. Gür et al. (2020) developed an interface that allows a keyboard and mouse to be moved through a device strapped to the head using neck movements. Although it was more accurate and agile than the solution proposed by Kawala-Janik et al. (2015), there was still the need for head and neck movements, and the accuracy and agility were relatively low.

It is essential to consider the possibility of developing a product optimized for people with limitations in fine movement in the upper limbs to provide superior navigation quality and greater comfort. The narrative literature review was conducted to synthesize information and interpret relevant knowledge for developing new projects and scientific advances. In this sense, this research contributed to creating an assistive technology that meets the needs of people with upper limb deficiency, improving their quality of life and social inclusion. Such narrative literature review suggests that there is a growing need for a peripheral that can be highly adaptable for each user with upper limb limitations due to the absence of currently available devices that allow adequate mechanical and virtual customization to ensure an optimized user experience.

Ideation: Drafts

An adapted joystick (handles) actuation system, which works as a mouse and keyboard, was chosen for the digital accessibility peripheral prototype. In addition, the navigation logic selected was based on the position of the two handles that move linearly in eight possible individual parts and 64 combinations. Several considerations were made to ensure the prototype's ergonomic design and user-friendliness. Firstly, the handles were meticulously shaped to promote comfortable gripping or resting of the hands. Additionally, ample spacing was incorporated between the holds to prevent potential collisions or accidental activation.

Furthermore, the overall design prioritized the ergonomic principles of movement, ensuring a seamless user experience. Additionally, the position and size of the buttons were carefully chosen to guarantee their easy identification and use. With these design choices, the user could navigate concomitantly using the mouse and keyboard without needing to remove the hands from the handles and without the need for fine movements. The adapted joystick actuation system was selected based on the biomechanical requirements of the volunteer, who needed to avoid fine upper limb movements. The navigation logic of the system was based on the position of two handles that can move linearly in eight individual parts and 64 possible combinations. The handles were designed with ergonomics and ease of use in mind, featuring large spacing between them and carefully chosen button positions and sizes. These design choices enable users to navigate with the mouse and keyboard simultaneously without requiring fine movements. The peripheral's functionality was based solely on the position of the two handles, eliminating the need for fine movements, such as pressing a button on a traditional keyboard, while providing speed and precision. Figure 3 illustrates the simple electronic schematic depicting the connection of the joysticks to the main board, exemplifying the ease of replication of this device.

Prototyping: Pilot study

The mechanical development of the prototype involved the creation of the 3D model of its final structure, manufactured by 3D printing (Figure 4). The system consists of the base, two handles acting as linear joysticks, a cover for sliding the handles, a TPU adapter inside the handle, the controller board, the joystick modules, wires, and the USB cable. The 3D model was created considering the combination of the module of a commercial joystick with a microcontroller and a solution for the adaptation of axial movement (initially performed by the commercial module) to the linear motion performed by the handle. This translation of movement is possible due to the elastic properties of a flexible ring, a link between the handle and the socket.

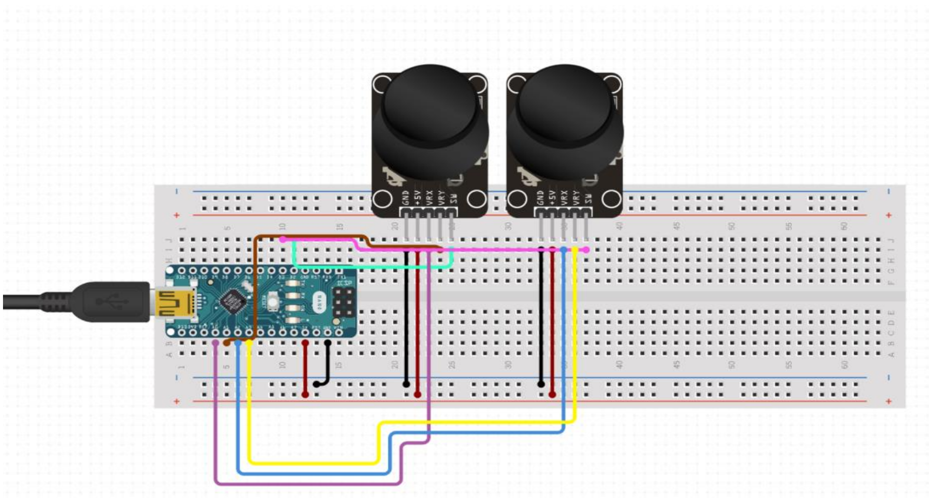

Figure 3. The internal electronics of the assistive peripheral. The development board, shown in blue, is connected to the joystick pair and linked to a computer through a USB cable.

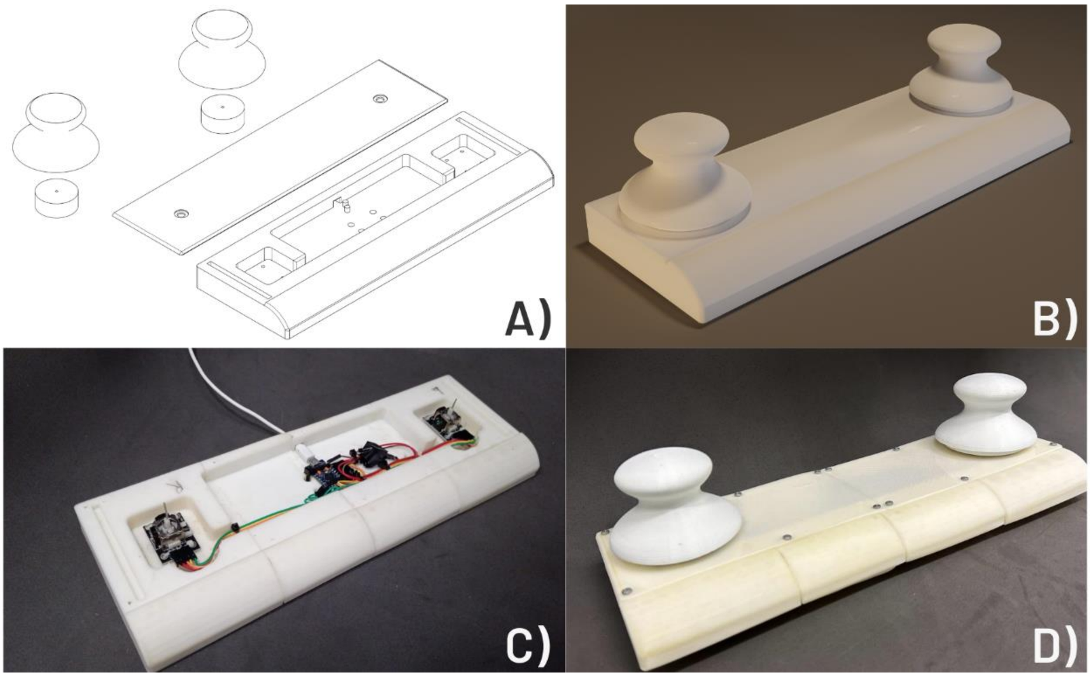

Figure 4. A) Peripheral prototyping stages: Exploded technical drawing of the physical structure of the assistive peripheral prototype. B) Rendered 3D model of the assembled prototype body. C) Manufactured physical prototype of the assistive peripheral with sensitive internal electronics. D) Assembled and ready-to-use assistive peripheral.

The prototype body was manufactured in ABS, aiming for the possibility of post-printing work; since this was the first printed prototype, it is natural that changes are necessary after manufacturing, such as sanding, filing, drilling, and cutting. TPU adapters were also manufactured for use with the handle. By itself, the handle could not transmit the movement demanded to the joystick module since it has a lever that operates in radial directions. Therefore, using a flexible material was essential for translating the linear motion performed by the handle to the radial movement required by the joystick module. However, with the current implementation of mouse mode, the product is already usable for essential functions, such as web browsing, writing through virtual keyboards, and using simple digital games.

Additive manufacturing was chosen as the fabrication method for the device body due to its popularity (which provides cheaper and more intuitive printer options to the public for homemade assistive devices) and manufacturing precision, which would only be possible to guarantee with specialized labor in manual methods. Moreover, it was chosen because of the option of unique adaptation for each case, as modeling software can easily modify the model to meet the user's requirements. For instance, a user with less severe mobility restriction may prefer the traditional handle, while a volunteer with more significant movement limitation may prefer a handle that facilitates grip.

Design is crucial for comfort, ergonomics, precision, and technical adequacy in producing and developing a product. The prototype's width of 35 cm was chosen based on anatomical parameters, avoiding shoulder strain for the user if the prototype measured 24 cm in width (previously planned measurements). During modeling, rounded details were prioritized inside and outside the prototype to avoid sharp corners, which are characteristic of more outstanding defects during manufacturing, especially in low-cost printers. The prototype was designed to accommodate the chosen hardware, ensuring appropriate sizing of cover holes and strategically placing apertures in the prototype's body for attaching electronic components and wiring.

The modeling process prioritized utmost simplicity in assembly, catering to a non-specialized audience. Still, it is possible to optimize and facilitate the assembly process by using simpler models and materials less prone to problems in printing, such as warping and weakening, since the workability possibility of ABS will not be necessary for future production. Warping of ABS is especially visible on prototype borders. This problem can be corrected by substituting ABS with another type of polymer filament to print the device's body. Despite the relatively long printing time of approximately 33 hours, the reproduction of the parts proved to be faithful to the computational model, confirming the excellent precision and quality of the FFF additive manufacturing method (Zuniga, 2018). The long continuous printing time was circumvented by dividing the parts into pieces, which avoids the warping of straight parts (such as the base and the cover) and the possibility of discarding the amount due to failure during printing (due to adverse factors such as power outages).

The prototype's low mass (700 g) was also verified since its density is optimized for lightness and reduced energy consumption. In addition, the production cost was lower than other methods, such as manual labor or injection molding, making the additive manufacturing process a more accessible and viable option for low-cost assistive technology development. The prototype's dimensions and features were carefully designed to suit the user's specific needs, thus demonstrating the importance of a tailored approach in assistive technology development.

Compared to other peripherals in the literature analysed in this research, the resources applied in the developed device proved distinct and unique. Thanks to its customizability, the prototype can be easily adapted to meet the needs of individual users by modifying the embedded C++ code. Additionally, it is possible to alter combinations and program shortcuts to optimize the user's experience. One of the key advantages of this prototype is its ergonomic design, which allows users always to keep their hands on the handles, thereby increasing speed in switching between mouse and keyboard modes and improving navigation and typing accuracy.

The pilot study made it possible to identify several points that require improvement in future prototypes. These include needing larger handles with ergonomically suitable shapes to facilitate prolonged use. Additionally, it is recommended to increase the horizontal size to approximately 35 cm and adapt the axial movement system to linear movement. Such modifications would reduce the reliance on fine motor activities and emphasize larger muscle groups, typically less affected in cases of partial upper limb limitations (Meng et al., 2019).

Tests

The pilot prototype was evaluated by authors through bench tests, utilizing it on operational systems such as Linux and Windows desktop environments. The peripherals were used on flat surfaces (desk, table) and in the user's lap for 20 min. A significant limitation is a distinction between positions since typing accuracy was not achieved during the pilot prototype tests. This problem can be solved by placing a guide piece between the prototype lid and the module, leading the joystick tip in only one of the eight directions, eliminating ambiguities, and ensuring precise typing and navigation. The performance evaluation indicated a need for code adaptation. However, the code structure partially works in keyboard mode but works adequately in mouse mode, requiring calibrations, logic optimization, access layer implementation, and customizations according to the volunteer's needs.

Once the electronic components were chosen, the lid and handles were assembled accordingly. However, a minor warping issue occurred in the top cover, potentially caused by manufacturing defects such as inadequate bed adhesion and temperature variations. To address the flaws, the whole body was carefully repaired using a mini grinder to create necessary holes, and screws were employed for secure fixation. This process ensured a flat surface, allowing the handles to slide smoothly. After that, a USB cable was inserted into the board's output, and the code was later introduced into the prototype's assembled version. A change was made in the initial design of the handle and the TPU adapter to prevent the handle from escaping its fitting. This change helps the handle translate the radial movement produced by the commercial joystick (which requires fine movements, such as fingers and wrists) to the linear motion performed by the handle and its sliding on the prototype lid (an activity suitable for using large muscle groups).

The outcomes from the bench tests and cost analysis reveal that, even in its developmental stage, the prototype exhibits advantages compared to those scrutinized in the literature review presented in this study. For instance, the possibility of partial use of upper limbs for navigation, something that Cáceres et al. (2018) did not address by focusing on the user's eye movements. It is hoped that the advantages of this prototype can be refined in future research.

Final considerations

There is a growing demand for adapted assistive peripherals, as standardized options may only cater to various users with varying needs. Furthermore, the ergonomic aspect is often overlooked in favor of the functional element of reviewed products. Analyzing these demands resulted in a list of ideal requirements for constructing this prototype. The FFF additive manufacturing process was chosen as the fabrication method because it offers low operating costs and low labor specialization requirements and enables easy and rapid adaptation to different cases. Additionally, with its increasing popularity, additive manufacturing is becoming more accessible to the public in terms of price reductions and general availability (Gibson et al., 2021).

The ASAP project effectively addresses the pressing social challenge of digital accessibility for individuals with upper limb mobility limitations. By focusing on practical, real-world issues, the project actively enhances the quality of life for this community. Robust community engagement, including voluntary participation in testing and interviews, underscores the project's commitment to inclusivity. The explicit goal of promoting social inclusion aligns with the broader objectives of university extension, addressing societal disparities.

Interdisciplinary collaboration and a comprehensive literature review showcase a commitment to leveraging existing knowledge and expertise. The ASAP project demonstrates a vision for continuity and future development, with a commitment to ongoing extension activities and the development of new assistive peripherals aligning with sustainability goals. Moreover, this initiative aligns with research that contributes to current and future social inclusion for those with upper limb movement impairments. By developing customized computer peripherals for quadriplegic volunteers, the extension projects have shown potential to restore daily digital activities, enhancing independence and overall quality of life of people with upper limb disabilities.

Tailoring assistive technology to specific needs empowers individuals to engage in a broader range of everyday tasks, transcending technological innovation to offer a simple yet profound social enabler. It allows those with upper limb movement impairments to interact more fully within their communities, shifting from dependence to empowerment, exemplifying the potential of technology to foster a more inclusive and equitable society and making opportunities and experiences more accessible to all. Additionally, creating an extension project for the social inclusion of people with disabilities has immense potential to empower university students. It enables them to develop technologies that profoundly impact the daily lives of individuals outside the university who need specialized solutions unavailable in the market. The combination of the ASAP project and the broader research underscores the transformative and socially impactful role that technology and extension projects can play in promoting inclusivity and empowering individuals with mobility limitations.

Conclusions

Based on the initial pilot project findings, the university extension program ASAP has demonstrated a significant increase in experience and expertise in constructing functional and technologically mature prototypes. The project has successfully shown that it is possible to build complex prototypes using the available materials and structure within the Mao3D Extension Program and utilize additive manufacturing to design and develop various assistive technology devices beyond Mao3D's upper limb prosthetics.

The pilot project results have demonstrated the feasibility of utilizing low-cost and easily accessible additive manufacturing techniques to develop assistive technology devices that meet the specific needs and requirements of individuals with physical disabilities. This achievement marks a significant breakthrough in Mao3D's history as an Extension Program. ASAP can provide a novel and cost-effective means of addressing the complex challenges of developing adaptive and personalized devices for individuals with disabilities. Furthermore, the continuation of the ASAP project is anticipated to deliver an even broader range of peripheral devices for individuals with upper limb mobility impairments, including clinical trials and evaluations to assess the effectiveness and usability of the ASAP devices in daily life. These improvements will not only increase the independence and digital accessibility of individuals with disabilities but can also contribute to the overall advancement of assistive technology research and development. Moreover, the potential for future collaboration between the ASAP project and other academic and industry partners may pave the way for developing more advanced and sophisticated assistive devices to serve the needs of individuals with disabilities better.

In summary, the results of the ASAP pilot project have demonstrated the potential for additive manufacturing techniques to significantly improve the accessibility and functionality of assistive technology devices. By utilizing low-cost and easily accessible materials and incorporating innovative design strategies, the ASAP project represents a promising new approach to developing personalized and adaptive devices for individuals with physical disabilities.

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Author's Contributions

L.H.F. authored the textual composition; M.E.K. and D.S. undertook the conclusive review; M.E.K. and D.S. guided L.H.F. throughout the research; L.H.F. constructed the prototype, assuming the responsibility for conducting interviews and tests. M.E.K. and L.H.F. created the university extension project ASAP.

References

Bina, T. D. S., Kunkel, M. E., Ribeiro, R. C., Ribeiro, T. V., Silveira, H. D., Passoni, L. H. D. M., Gonçalves, I. T., & Rodrigues, S. M. S. (2020). Produção de próteses mecânicas 3d de membro superior para um caso de amputação bilateral infantil: desafios da reabilitação. In F. C. C. R. C. Ferrari (Ed.), *Processos de Intervenção em Fisioterapia e Terapia Ocupacional 2*. (pp. 185–198). 1st ed., Ponta Grossa-PR: Atena Editora. https://doi.org/10.22533/at.ed.44720071221

Bohorquez, J., & Montero, R. (2019). Board 1: Introduction to design thinking and human-centered design in the biomedical engineering freshman year. 2019 ASEE Annual Conference & Exposition Proceedings, 32161. https://doi.org/10.18260/1-2--32161

Brack, R., & Amalu, E. H. (2021). A review of technology, materials and R&D challenges of upper limb prosthesis for improved user suitability. *Journal of Orthopaedics*, 23, 88–96. https://doi.org/10.1016/j.jor.2020.12.009

Brown, T., & Katz, B. (2009). *Change by Design: How design thinking transforms organizations and inspires innovation*. New York: Harper Business.

Cáceres, E., Carrasco, M., & Ríos, S. (2018). Evaluation of an eye-pointer interaction device for human-computer interaction. *Heliyon*, 4(3), e00574. https://doi.org/10.1016/j.heliyon.2018.e00574

Dembo, R. S., Mitra, M., & McKee, M. (2018). The psychological consequences of violence against people with disabilities. *Disability and Health Journal*, 11(3), 390–397. https://doi.org/10.1016/j.dhjo.2018.01.006

Elsahar, Y., Hu, S., Bouazza-Marouf, K., Kerr, D., & Mansor, A. (2019). Augmentative and alternative communication (aac) advances: A review of configurations for individuals with a speech disability. *Sensors*, 19(8), 1911. https://doi.org/10.3390/s19081911

Fazan, L. (2021). *Desenvolvimento de um periférico para substituir o mouse e teclado convencional para pessoa com deficiência de membro superior* [Peripheral to replace conventional mouse and keyboard for upper limb disabled person.] Undergraduate Thesis, Federal University of São Paulo. Retrieved from https://repositorio.unifesp.br/items/cfe0270c-42be-4bd7-9927-d4a527428ed3

Fjeldvang, R. T., Nordaas, M. G., Von Tetzchner, S., & Stadskleiv, K. (2023). Measuring impact of augmentative and alternative communication interventions: Adapting the family impact of assistive technology scale for augmentative and alternative communication (FIATS-AAC-No) for use in Norway. *Augmentative and Alternative Communication*, 1–11. https://doi.org/10.1080/07434618.2023.2170276

Gibson, I., Rosen, D. W., Stucker, B., Khorasani, M., Rosen, D., Stucker, B., & Khorasani, M. (2021). *Additive manufacturing technologies*. (Vol. 17, pp. 160-186). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-56127-7

Göttgens, I., & Oertelt-Prigione, S. (2021). The application of Human-Centered Design approaches in health research and innovation: A narrative review of current practices. *JMIR MHealth and UHealth*, 9(12), e28102. https://doi.org/10.2196/28102

Gugan, D. (2020). An embedded-systems approach to the socio-economic cycles of the world system. In E. Mielants, & K. Bardos (eds.), *Economic Cycles and Social Movements*. (pp. 134-145). Abingdon: Routledge.

Gür, D., Schäfer, N., Kupnik, M., & Beckerle, P. (2020). A human–computer interface replacing mouse and keyboard for individuals with limited upper limb mobility. *Multimodal Technologies and Interaction*, 4(4), 84. https://doi.org/10.3390/mti4040084

Jin, Y., Plott, J., Chen, R., Wensman, J., & Shih, A. (2015). Additive manufacturing of custom orthoses and prostheses – A review. *Procedia CIRP*, 36, 199–204. https://doi.org/10.1016/j.procir.2015.02.125

Kawala-Janik, A., Podpora, M., Gardecki, A., Czuczwara, W., Baranowski, J., & Bauer, W. (2015). Game controller based on biomedical signals. 2015 20th International Conference on Methods and Models in Automation and Robotics (MMAR), 934–939. https://doi.org/10.1109/MMAR.2015.7284003

Khan, M. S., & Sentosa, I. (2018). Exploring the role of transformational leadership in human capital effectiveness: Empirical evidence from the Malaysian healthcare sector. *World Journal of Entrepreneurship, Management and Sustainable Development*, 14(2), 191-204. https://doi.org/10.1108/WJEMSD-10-2017-0075

Kunkel, M. E., Abe, P. B., Pasqua, M., Gonçalves, I. T., Pinheiro, L. D. M., & Rodrigues, S. M. (2019). Mao3D - Protetização e reabilitação de membro superior adulto com a tecnologia de impressão 3D. In N. A. Cardoso, R. R. Rocha, & M. V. Laurindo (Eds.), A produção do conhecimento na Engenharia Biomédica (pp. 14–29). 1. ed., Ponta Grossa-PR: Atena Editora. https://doi.org/10.22533/at.ed.8281901063

Kunkel, M. E., Sauer, A., Bina, T., Baron, B., & Fazan, L. H. (2022). Internacionalização do Programa de Extensão Mao3D da Unifesp: Experiência na Alemanha. In T. Stumpp, M. Rosalen, & E. Viesba (Eds.), Extensão Universitária: Experiências na integração Universidade- Sociedade. (pp. 385–396). Diadema: V&V Editora. https://doi.org/10.47247/ts/88471.84.5.38

Mao3D. (2023). *Home*. Retrieved from https://www.mao3d.com.br/

Meng, Q., Xie, Q., Shao, H., Cao, W., Wang, F., Wang, L., Yu, H., & Li, S. (2019). Pilot study of a powered exoskeleton for upper limb rehabilitation based on the wheelchair. *BioMed Research International*, 2019, 1–11. https://doi.org/10.1155/2019/9627438

Moon, N. W., Baker, P. M., & Goughnour, K. (2019). Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors. *Journal of Rehabilitation and Assistive Technologies Engineering*, 6, 205566831986213. https://doi.org/10.1177/2055668319862137

Shih, C.-H. (2012). A finger-pressing position detector for assisting people with developmental disabilities to control their environmental stimulation through fine motor activities with a standard keyboard. *Research in Developmental Disabilities*, 33(5), 1360–1365. https://doi.org/10.1016/j.ridd.2012.03.011

Zuniga, J. (2018). 3D Printed Antibacterial Prostheses. *Applied Sciences*, 8(9), 1651. https://doi.org/10.3390/app8091651

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