https://doi.org/10.47456/bjpe.v10i5.47022 ARTIGO ORIGINAL | OPEN ACCESS

DEVICE PROTOTYPE TO ASSIST HAND AMPUTEES IN PERFORMING ADMINISTRATIVE TASKS

DISPOSITIVO PARA REABILITAÇÃO INDIVIDUAL DE DEDO DA MÃO

DISPOSITIVO PARA LA REHABILITACIÓN INDIVIDUAL DE LOS DEDOS DE LA MANO

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ARTIGO INFO.
Publicado: 06.12.2024

KEYWORDS: Device; Administrative tasks; Assistive technology.
PALAVRAS-CHAVE: *Dispositivo; Tarefas administrativas; Tecnologia assistiva.*
PALABRAS CLAVE: *Dispositivo; Tareas administrativas; Tecnología Asistiva.*

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ABSTRACT

There is a need to include people who have suffered amputation of one of their hands in the labor market, which can be facilitated by means of a device that helps perform daily activities in an office. This subject is of interest to organizations due to the legal requirements for hiring people with disabilities or because of talent retention that improvements in working conditions produces. This study presents the development of a prototype that enables hand amputees to use a mouse for computer tasks and transport boxes and light equipment. The prototype successfully enables users to manipulate a mouse and perform basic computer tasks. The prototype's design also allows for keyboard use, employing a similar lever system to activate keys. Initial observations suggest the device could enhance workplace independence for hand amputees. The prototype design was informed by the assumption that users would possess normal elbow and shoulder function or have the potential to regain these functions through physical therapy.

RESUMO

Existe a necessidade de incluir no mercado de trabalho pessoas que sofreram amputação de uma das mãos, o que pode ser facilitado por meio de um dispositivo que auxilia na realização de atividades diárias em um escritório. Este tema é de interesse para as organizações devido aos requisitos legais para contratação de pessoas com deficiência ou por causa da retenção de talentos que as melhorias nas condições de trabalho proporcionam. Este estudo apresenta o desenvolvimento de um protótipo que permite a amputados de mão usar um mouse para tarefas de computador e transportar caixas e equipamentos leves. O protótipo possibilita com sucesso que os usuários manipulem um mouse e realizem tarefas básicas de computador. O design do protótipo também permite o uso do teclado, empregando um sistema de alavanca semelhante para ativar as teclas. Observações iniciais sugerem que o dispositivo pode aumentar a independência no local de trabalho para amputados de mão. O design do protótipo foi baseado na suposição de que os usuários teriam função normal do cotovelo e do ombro, ou o potencial de recuperar essas funções por meio de fisioterapia.

RESUMEN

Existe la necesidad de incluir a personas que han sufrido la amputación de una de sus manos en el mercado laboral, lo cual puede facilitarse mediante un dispositivo que ayude a realizar actividades diarias en una oficina. Este tema es de interés para las organizaciones debido a los requisitos legales para la contratación de personas con discapacidad o por la retención de talento que produce la mejora de las condiciones de trabajo. Este estudio presenta el desarrollo de un prototipo que permite a los amputados de mano utilizar un ratón para las tareas informáticas y transportar cajas y equipos ligeros. El prototipo permite con éxito a los usuarios manipular un ratón y realizar tareas informáticas básicas. El diseño del prototipo también permite el uso del teclado, empleando un sistema de palanca similar para activar las teclas. Las observaciones iniciales sugieren que el dispositivo podría mejorar la independencia en el lugar de trabajo para los amputados de mano. El diseño del prototipo se basó en la suposición de que los usuarios tendrían una función normal del codo y el hombro, o tendrían el potencial de recuperar estas funciones a través de fisioterapia.

INTRODUCTION

Using devices to reduce the impacts on the quality of life, caused by insufficient body parts, has been practiced since ancient history. According to Lienhard (2002), archaeological finds demonstrate the use of prostheses by the ancient Egyptians in the 10th century BC.

Since then, advances in science have helped people carry out a wide range of activities. Likewise, assistive technologies have also advanced so that people with some type of disability can carry out their activities with greater independence, which increases their autonomy, improves their quality of life, and consequently increases their self-esteem (BERSCH, 2017).

However, access to assistive technologies remains restricted to a very small portion of society. According to the World Health Organization (WHO) (2017), only 10% of the population with special needs has access to these technologies, and, according to the same document, most people who need it do not have their own income and have a low family income.

However, according to Hanley (2009), most people with upper limb loss have chronic pain or even more serious problems caused by ergonomics in carrying out their activities, whether at work or in their daily lives, and these pains are determining factors in the individual's employability and participation in social activities.

According to Resnik (2019), a solution to the problem is the use of prostheses, because, in addition to improving the user's performance in carrying out their daily activities, these devices help to prevent cumulative trauma and other disorders of repetitive strain injuries and forced posture. In addition, prostheses reduce the occurrence of pain not only in the region of disability, but also in the back and neck.

However, studies by Resnik (2019) also point out that most users are not satisfied with their prostheses, which explains the high rate of abandonment, showing that the main reasons that lead to such abandonment are the limited functionality of the devices currently available, the sheer weight and the user interface, as each body has different dimensions and anatomy and most models do not have many adjustments. Therefore, there is a need for the continuous development of functional, economically viable prosthesis models that help people with disabilities to perform their activities.

According to Cobos (2010), the human hand is endowed with great versatility and dexterity. It is the main characteristic that distinguishes human beings from other existing animals. Comprising 27 bones and 17 joints and with 24 degrees of freedom, it is a huge challenge to create a device capable of performing this wide range of motion in an agile and precise manner.

The challenge of developing a device that can partially replace the lack of an upper limb can become less complex if the focus of the device is to assist in the performance of tasks present in daily work activities, thus reducing the number of parts and degrees of freedom needed for its construction and, consequently, its cost.

Thus, this work presents a proposal for a device specialized in performing simple administrative tasks, aiming at an affordable construction cost, so that they can be purchased by contracting companies, or by the users of the models themselves. The presented design is a simple and functional device that can help people with disabilities in upper limbs, particularly for cases of transradial amputation, to carry out administrative tasks.

UPPER LIMP PROSTHESIS

Using prostheses as an option to replace part of a person's body has been reported since ancient Egypt. Considering advances in science, new models have been developed over time. However, for most of that time, prostheses had more aesthetic than functional function. It was during the Renaissance, between 1400 and 1800, that the first articulated prostheses capable of performing simpler grips appeared (Norton, 2007).

From the new, available amputation techniques, new varieties of mechanisms capable of articulating the replacement limb have emerged. These models were mainly used by military officers who ended up losing parts of their bodies in battle. An example is the iron hand of Gotz, a German imperial knight who lived in the 15th and 16th centuries, who, when he lost his right hand in the siege of Landshut in 1504, had it replaced by a prosthesis capable of holding a shield or even a feather (Adela, 2017).

In modern times, due to the first and second world wars, there was an increase in the number of amputees around the world, which generated a very high demand for more effective prosthesis models to enable veterans to reintegrate into the labor market (Araújo, 2017).

After their economies were devastated, aid to ex-combatants was not possible, and many had even lost their families and were unable to support themselves. In this context, Araújo (2017) points out the emergence of the concept of prostheses not to disguise the disability, but to allow these people the possibility of being reintegrated into the labor market.

Currently, in commercial upper limb prostheses, devices are made of high-tech materials, such as titanium and carbon fibers, and have sensors capable of capturing muscle contraction to carry out their movements. One example is the Össur© i-Limb© prosthesis, which allows you to adjust the type of grip to be performed with gestures and internal software that help to make grips more agile and firm.

On the other hand, aiming at the manufacture of more accessible prostheses, voluntary organizations have made inexpensive hand prosthesis designs available manufactured by 3D printers with open-source designs, that is, anyone who has access to additive manufacturing technology can use these designs and manufacture hand prostheses for their community. An example of this type of organization is e-NABLE, which has registered volunteers from around the world who support people seeking upper limb prosthetics for free (Enablingthefuture.Org, 2019).

Currently, in the literature, several studies have supported the search for cheaper and more functional models of low-cost upper limb prostheses, such as Stoppa (2017), who developed a model with geometric configurations obtained by scanning a human hand with grips performed by servomotors controlled by voice command, as well as weight and cost reduction due to using additive manufacturing.

Other studies, such as Nagaraja (2016), have sought to assess the levels of satisfaction of low-income upper limb prosthesis users regarding usage patterns, reasons for non-use and design improvement needs, among other factors. The results obtained demonstrate a high demand for improved functionality of the models, more comfortable fitting and more affordable costs.

Tiele (2017) worked on the development of an upper limb prosthesis model and accessories to support cyclists and achieved satisfactory results for recreational and rehabilitation purposes. However, the author also pointed out the need for improvement, such as using lighter and cheaper materials to make the model.

Prakash (2019) sought to develop a low-cost electromyography sensor to control the movement of the prosthesis. The proposed model was tested and, in addition to the reduced cost, the sensor showed greater sensitivity than current commercial models.

ERGONOMICS IN ADMINSTRATIVE TASKS

According to Vidal (2012), the term ergonomics originates from the European Industrial Revolution in 1857, when the Polish scientist Wojciech Jastrzebowski established ergonomics as science applied to work, which aims to understand human activity in terms of effort, thinking, relationships and dedication. However, the concept of ergonomics has existed since the beginning of civilization, as shown by archaeological findings in which the Egyptians had recommendations on tool manufacturing for civil construction, such as documents on the layout of pyramid construction sites.

For a person with a disability, concern with ergonomics is even more important. As Cabral (2008) points out, it is essential to include universal design concepts to enable people with disabilities to overcome their disabilities and replace them with opportunities. Otherwise, there is a risk of suppressing the abilities and potential of these people, underestimating them, or worse, causing the progression of present injuries or even the emergence of new injuries.

According to Costa (2016), ergonomic risks associated with administrative tasks are related to long periods of sitting and the posture adopted in carrying out activities, in addition to the conditions offered by the space for carrying out the work. He also states that injuries and musculoskeletal pain are common among office workers, the most common being: back and upper limb pain, as well as eye fatigue. The cause of pain is related to inadequate posture and workstation and lack of training in handling furniture and equipment in the area.

According to the results obtained in his research, Hanley (2009) points out that the same pains are also more common among people who do not have upper limbs. The main causes of pain in these people are related to excessive use of the residual limb and the aggravation of pre-existing arthritis. Therefore, it can be hypothesized that this condition can worsen existing injuries or develop new injuries in a person without an upper limb who will be occupied in a job related to administrative tasks.

One of the results obtained by Costa (2016) in her research was a survey of the main activities carried out in public offices in various positions. The author points out that there was no great variation in these activities between positions and tasks were considered as standard.

Among these standard tasks, using a mouse and fitting ergonomics for orthogonal support were taken as requirements to develop the prototype, which allows the user to carry objects in a polyhedral way, such as boxes and computers. Developing a device that partially replaces an upper limb can be simplified by focusing on assisting with specific workplace tasks. This approach reduces the complexity of the device, lowering both the number of parts required and the overall cost.

DEVICE DESIGN

The prototype design was informed by the assumption that users would possess normal elbow and shoulder function or have the potential to regain these functions through physical therapy.

However, regarding the movements that the device allows, a mouse can be used to avoid wrist or rotation movements of the forearm. Moreover, lifting objects with both hands is possible as the dominant hand can adjust the level to ensure a good fit between the object and the device.

When looking for a light and economically viable material to manufacture the device, upper limb prosthesis designs that can be manufactured by open-source 3D printing, available on the Internet, were evaluated.

Thus, analyzing the existing models, it was decided to use the user coupling system, from the model UnLimbited Arm v2.1 - Alfie Edition of e-NABLE (Enablingthefuture.Org, 2019).

However, the hand and fingers will not be used, as the device will be attached to the end to carry out the activities, which is the focus of this study.

To build a device that meets the proposed objective of being able to handle a mouse and having an orthogonal fitting capable of supporting rectangular objects, a configuration for the device was designed, so that it is simply attached to the mouse. positioning and light pressure (fitting system) and uncoupled using a side button.

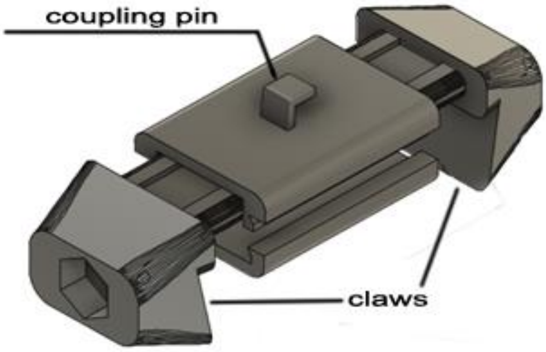
Mouse handling comprises two mechanisms: one that helps with moving the mouse on a work surface and the other that activates the mouse buttons.

MOUSE HOLDING SYSTEM (MHS)

This is a system that makes it possible to fit the prototype to the most common mouse models. It consists of an adjustable accessory that holds the mouse called a mouse clip (MC) and can be easily docked and undocked from the prototype without jeopardizing its handling.

This accessory can connect to a mouse ranging from 40 to 65mm in width, which is the measurement range of the most common models of small and medium-sized mice (Figure 1). The length of the mouse does not interfere with the use of the accessory.

Figure 1. Mouse clip



Source: The Authors.

The coupling pin interfaces with the “hand” of the prosthesis. The placement of this pin in the hand will activate a spring system holding it to the accessory, a button on the side of the hand allows disengagement between the two pieces.

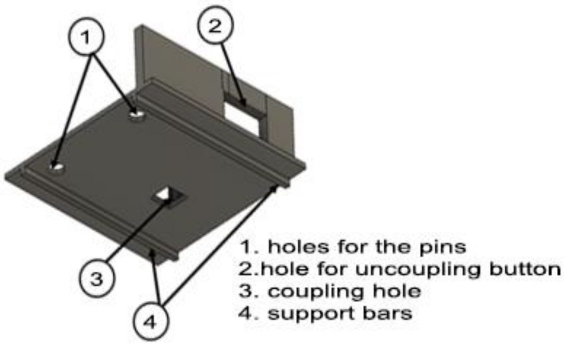
A spring inside the MC allows the claws to adjust their distance to fit the mouse being used (Figure 2). Most mouse models have a curved side configuration, therefore, to improve the grip between the mouse and the MC, it is suggested that a 1/8-inch self-adhesive foam be glued to the inner surface of the grips used in the device's elbow support for greater user comfort.

Figure 2. MC docked over the mouse

Source: The Authors.

The main base of the prototype has two bars that support the side of the MC body, keeping the mouse fixed and preventing the coupling pin from accidentally detaching (Figure 3). To receive the coupling pin, there is a hole in the base and two other holes are used to pass the pins to activate the left and right mouse buttons. Mouse scrolling was not foreseen.

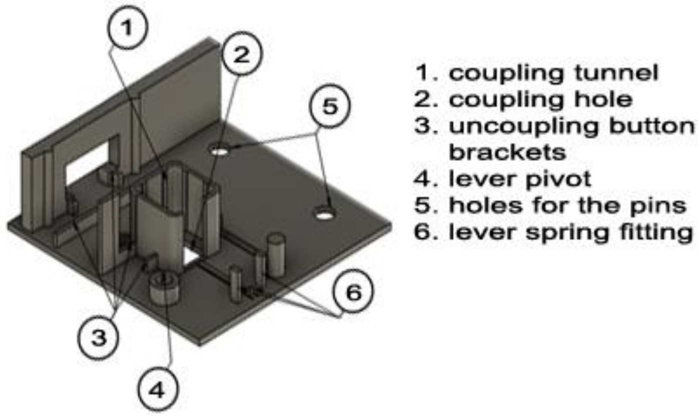
Figure 3. Exterior of the main base of the prototype



Source: Authors.

On the inner face of the base are the support structures for the parts that comprise the coupling device to the MC (Figure 4).

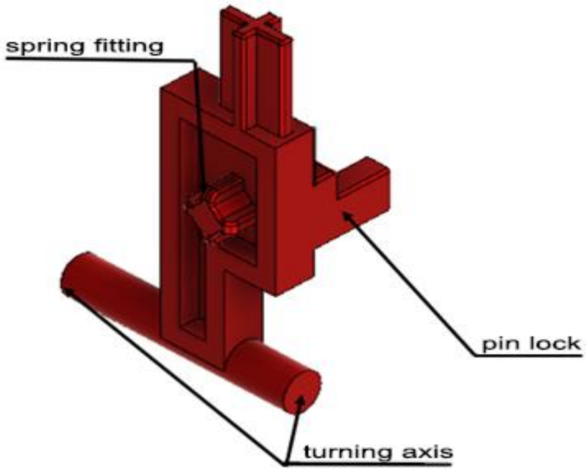
Figure 4. Interior of the main base of the prototype



Source: Authors.

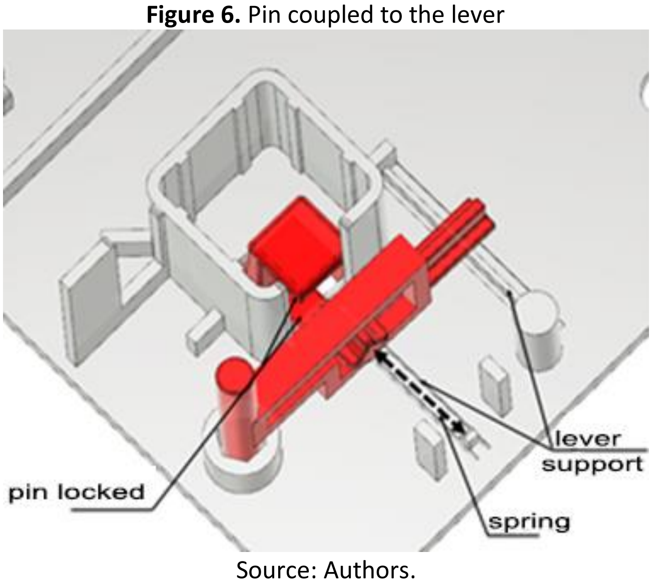
This device is a lever (Figure 5) that pushes (spring) a lock onto the coupling pin (Figure 6). A block, pushed by a second spring, prevents the lever from being actuated until the pin is inserted into the hole and closes the coupling hole when not in use.

Figure 5. Lever



Source: Authors.

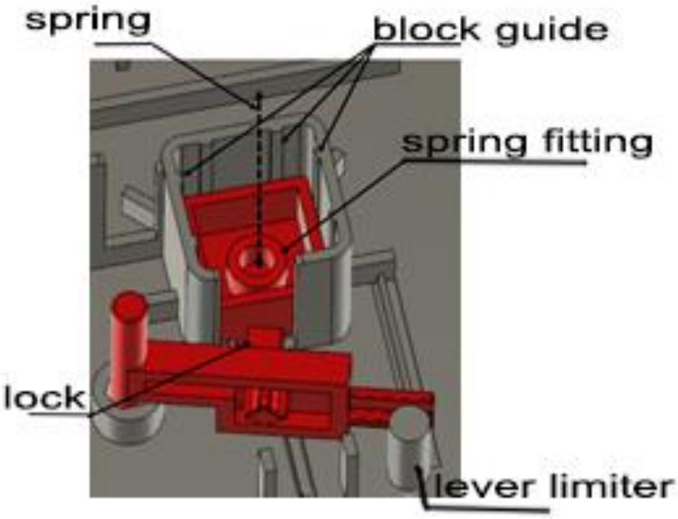
Figure 6. Pin coupled to the lever



Source: Authors.

The geometry of the inner side of the coupling tunnel acts as a guide and ensures that the block does not fall off its axis. The closure block is hollow and has a spring clip on the back (Figure 7).

Figure 7. Locked lever

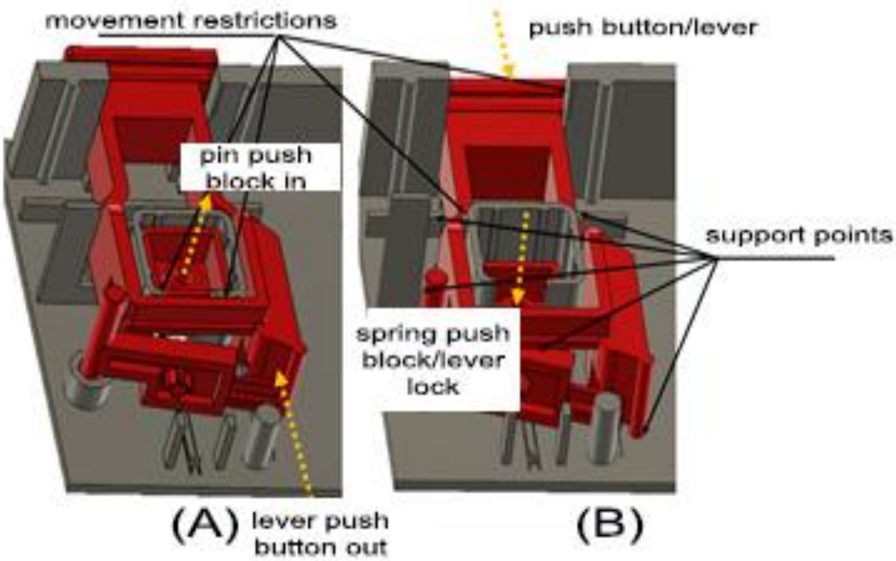


Source: Authors.

The MC is decoupled by a button that is pushed out by the lever when it is activated. Pressing the button pushes the lever back, releasing the MC pin, returning the closing block to its original location.

The button is supported on points of the structure and its movement is limited according to its position. When coupled, its movement is restricted by the lever and the coupling tunnel wall and when uncoupled, its movements are limited by the lever, the outer base wall and the other side of the coupling tunnel (Figure 8), preventing the button from moving away from its axis.

Figure 8. Button and lever in the coupling (A) and uncoupling (B) positions



Source: Authors.

Once the mouse is attached, the user can move it over the work surface, positioning the computer cursor at the desired location on the screen. This movement must be performed using the elbow or shoulder. The flexion-extension of the elbow can help this movement, but for it to occur in the transverse axis (on the work surface) the shoulder must remain flexed throughout the period of use.

Moving the mouse proved to be more viable through the shoulder, because, considering a suitable workstation, in which the arm and elbow are supported on a rest with the same height as the work table, the mouse can be moved by the shoulder through humeral rotation, which is the rotation of the upper arm on its own axis This rotation, combined with slight flexion-extension of the shoulder on the sagittal axis, ensures accurate cursor positioning over any point on the computer screen.

MOUSE BUTTON ACTIVATION SYSTEM

For the mouse button click system, the device must be able to transfer the movement of the shoulder or elbow to activate the left and right mouse buttons in a functional way. When the pins are positioned over the mouse buttons, a few millimeters of movement are enough to activate the buttons. However, this should be followed up by an occupational therapist so as to check the device is being used correctly, as well as any new assistive technology.

By analyzing the movements, as well as the movement of the mouse, activating the buttons using the elbow is a problem, because the elbow extension is prevented by the work surface and the flexion performed with the mouse attached would lift it, thus being able to remove the cursor from the desired point.

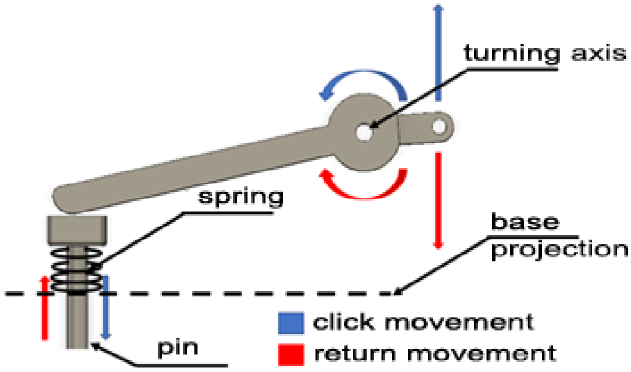
The forearm region of the device is secured to the body by one-inch-wide Velcro over the forearm stump. Thus, pronation and supination can be impaired or cause some discomfort due to the Velcro during its rotation. In addition, many amputees do not have the radius in the stump, which prevents pronation and supination movements and limits the applicability of the proposed model.

Regarding shoulder movements, flexion-extension performed on the sagittal axis and axial arm rotation (humeral rotation) are already being used to move the mouse over the work surface. Flexion and extension performed in the horizontal plane of the shoulder require the shoulder to be abducted and not supported on the work surface.

From the adduction and abduction movements of the shoulder in the frontal plane, a mechanism capable of transferring these movements to the pins, which will click the mouse buttons, was created.

The pins are positioned over the holes contained in the base and to make the pins recoil after the click, a spring is positioned between the pins and the inner face of the base. There is a groove in the base to help position the spring correctly. The pins have a wide backrest for positioning the spring and to facilitate the activation of the pins, which is made by rods that rotate around a pivot positioned over the device handle (Figure 9).

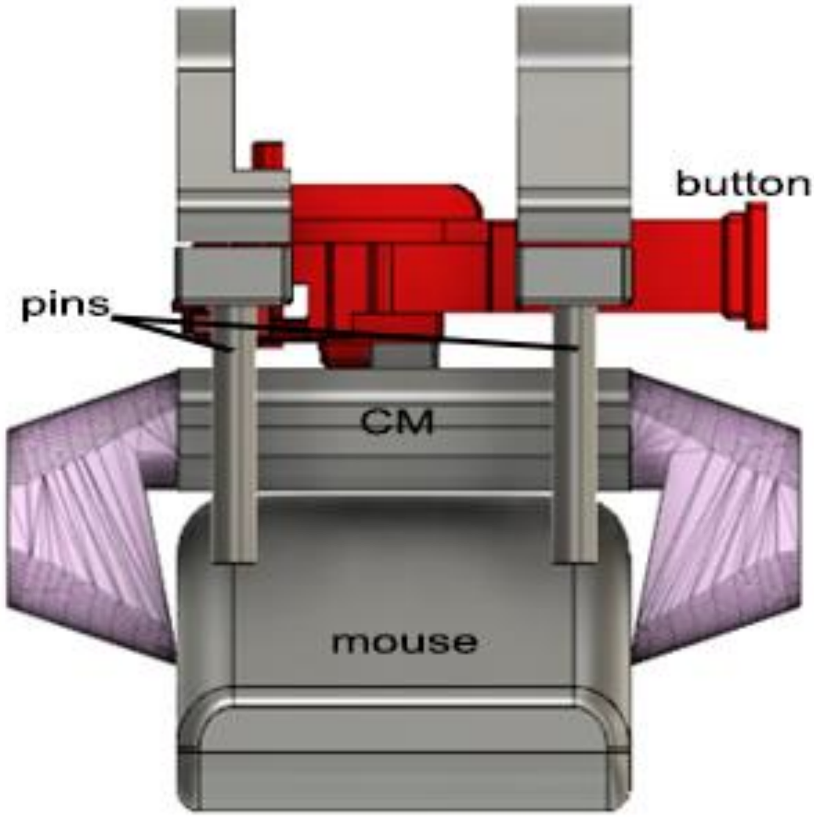
Figure 9. How the rods work



Source: Authors.

The rod that actuates the right button is shorter in length compared to the rod of the left button, allowing the lever and coupling button to work without any interference (Figure 10).

Figure 10. Front view of the mouse under the pin system and MC



Source: Authors.

The pivoting shafts of the rods are positioned in transverse holes in the handle of the device and fixed by screws that are the pivots of the rods and help to secure the top cover of the device.

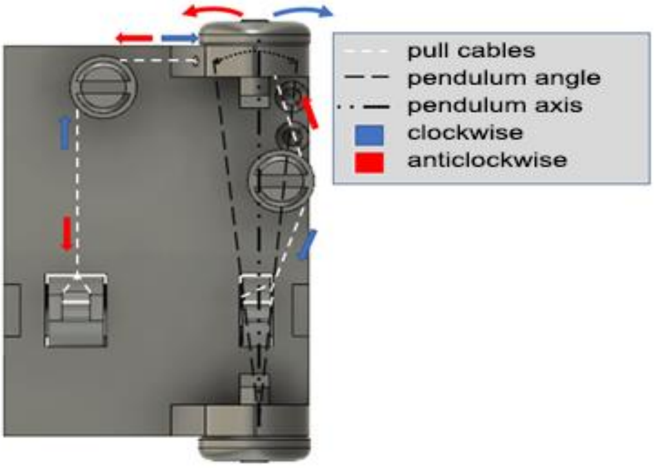
A cable system makes the traction activate the rods, led until the upper fitting of the handle through lateral holes and attached to the pin that holds the forearm to the handle.

The lower socket of the forearm is threaded on its two sides, allowing the pin to be tilted on either side, fulfilling its function as a fixed point of a pendulum.

The upper forearm socket has a path through which the pin can slide, in which the center position is neutral, where there is no mouse click; moving the pin to either side triggers the mouse click in the opposite direction to the pin's movement.

With the rod traction cables fixed to the upper pin, the rotation of this pin counterclockwise pulls the wire that is attached to the right rod, making the mouse click and releasing the wire that is attached to the left rod, taking it to the original position. Rotating the pin clockwise causes the opposite effect, clicking the left button and loosening the right side (Figure 11).

Figure 11. Pin-to-rod movement transfer scheme



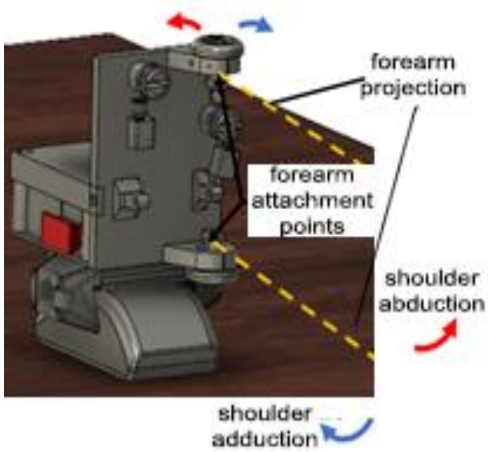
Source: Authors.

Pulleys produce smoother angles for working the ropes and reduce friction with parts, preventing breakage or premature wear of the rope. These pulleys consist of a pin and a pulley, which is fitted to the pulley by pressure.

To adjust the length of the cable and the proper tension to keep the pin and the rods in the neutral position, a simple adjustment system was added using a screw that can increase or decrease the length of the cable, thus adjusting it to the desired size.

Finally, with the device attached to the mouse (supported on a table), the shoulder abduction movement moves the system by clicking on the right side of the mouse while the shoulder adduction makes the click on the left side (Figure 12).

Figure 12. Transfer of shoulder movement to the click system

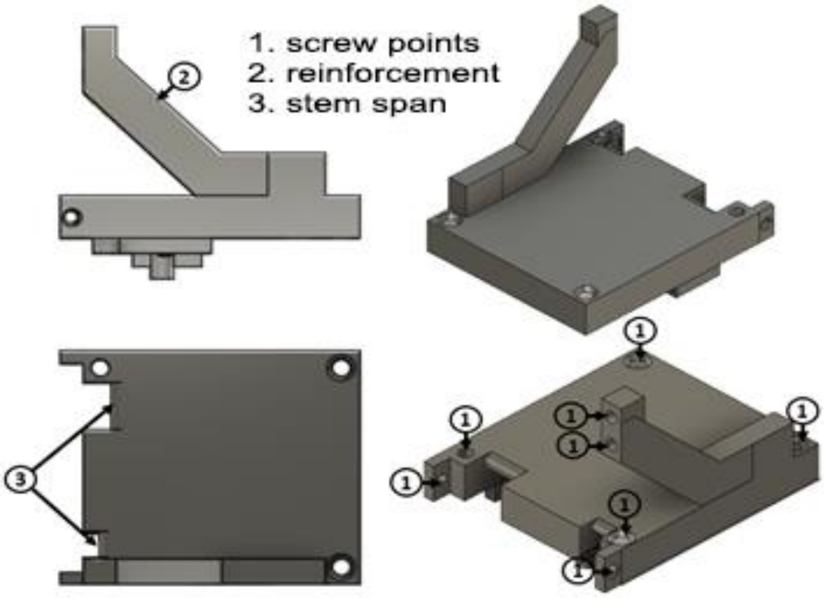


Source: Authors.

FLAT TOP SURFACE

As the device user can handle the mouse and keyboard set, the next functionality of the device is evaluated, which is being able to support the transport of objects that require both hands, such as a box or a computer. To do this, the top face of the device must be flat, allowing a better fit with polyhedral objects, such as the examples above. In addition, a reinforcement was included on the external face of the device (Figure 13), preventing the object from sliding along the side.

Figure 13. Views of the top surface of the device cover



Source: Authors.

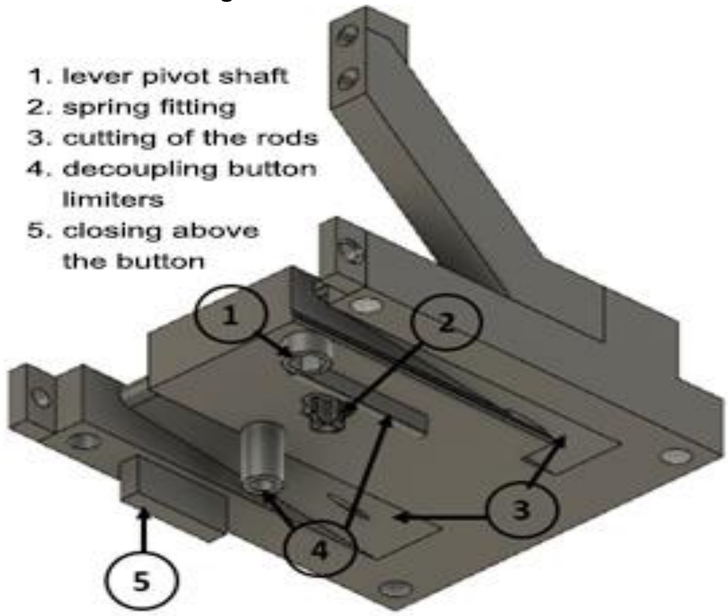
This system does not allow the user to lift boxes that are resting on the floor or objects that are above the level of his/her head with both hands, but it does allow him/her to carry boxes that are stored on shelves and computers that are supported on tables, as this fitting is limited to supporting the base of the objects and does not have a claw that can hold objects by grip.

In addition, the extension of the stump helps users to carry out tasks that would require bending the shoulder and spine to use it, supported on a sheet of paper to facilitate writing or pushing an object on the table, reducing the incidence of pain in the shoulders and spine.

The device cover fits the other parts. To do this, there are several points for fixing screws (M4x15). To reinforce the device's tensile strength, as the loads will be positioned on the upper surface, a reinforcement bar has been included that will be attached to the handle by two screws, preventing objects from sliding along the side.

Several details are on the inner face of the cover to support the two previous functionalities, the SAM and the movement of the rods. Two spaces were opened in the part that touches the wrist to allow the placement of the rods. In addition, cutouts were made inside to allow the movement of the rods (Figure 14).

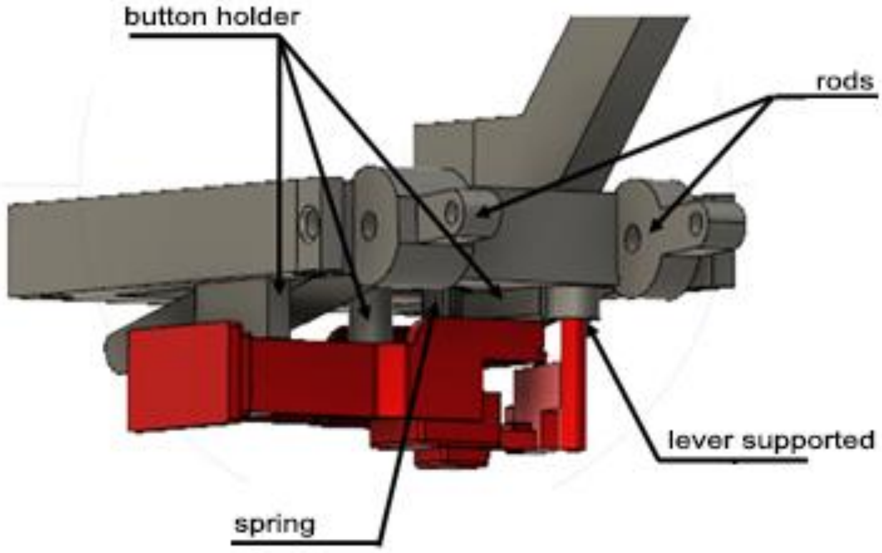
Figure 14. Inner face of the lid



Source: Authors.

As the base of the device has a cutout for the positioning of the coupling button (Figure 15), an elevation on the inner face of the cover closes the socket of the button. Furthermore, it prevents the button from coming off its working axis. Two other bars serve as a guide for the button on its path, limiting its movement and preventing it from falling off its axis.

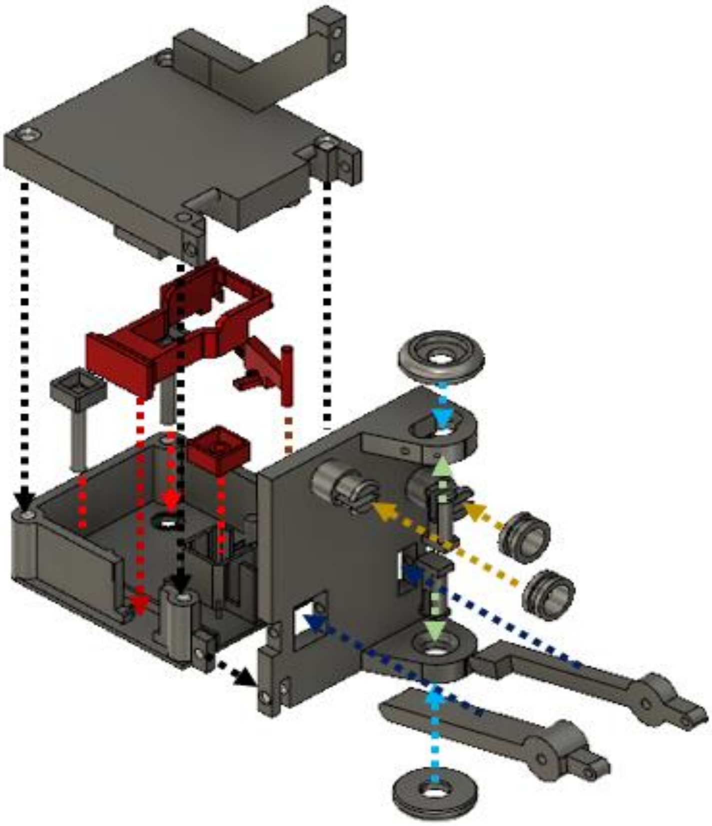
Figure 15. Set of parts supported under the cover



Source: Authors.

The device parts need to be adjusted so that they can be fitted or screwed together and so that they can be produced through additive manufacturing. After being analyzed, it was found that, except for the base, all the parts already had their fixation points. The enlarged view of the device is shown in Figure 16.

Figure 16. Enlarged view of the device



Source: Authors.

CONCLUSIONS

The quality of life of a person with an amputated upper limb can be improved by their inclusion in the labor market. This is due to the increase in income, the individual's participation in social activities and self-esteem. The development of tools that can improve this inclusion has been discussed by stakeholders.

The results obtained in this work can contribute to this end, as it is a low-cost solution, which can be acquired by employers, by institutions that support people with disabilities or even by the disabled, in addition to stimulating possibilities for the development of others. models of prostheses aimed at carrying out work in the most diverse areas.

The developed prototype can perform the mouse handling functions using the buttons and is able to hold it firmly to move it on the work surface. In addition, it can also help to lift boxes and other equipment that require both hands in transport and serve as an extension of the stump when carrying out simpler tasks, such as supporting the stump on a sheet of paper to facilitate writing.

Additive manufacturing proved to be a great ally in the development of prototypes quickly and at low cost, which is of paramount importance in the development of prostheses and orthotics due to the variations in dimensions present in the human body and the disability itself, which can affect different ways.

However, Costa (2017) emphasizes that the inclusion of upper limb prostheses in patients precedes a process of muscle rehabilitation and adaptation, which must be accompanied by a professional in this area. Thus, it is suggested that further studies can aim to validate the prototype in the dimensions of analysis of physical therapy and prosthetics.

Other suggestions for improving the product follow on improving the anatomical design of the prototype, seeking a format closer to human anatomy, or even evaluating the parts for mechanical strength, since the user will apply loads on the model, in the parameterization of the dimensions of the model so that print drawings can be generated for any dimensions of the user's body, and, finally, in evaluating the performance of prototype users in relation to the use or not of the proposed model.

Validation of the prototype proposed to be used in the market still depends on tests to evaluate the performance when carrying out tasks and to evaluate the resistance and durability of the parts during the work. It is essential for a physiotherapist to follow up the adaptation period of the model to recover amputated limb musculature.

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