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Design for disability: Integration of human factor for the design of an electro-mechanical drum stick system

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Abstract

Traditionally, designers imagine, design and manufacture products or interfaces for able-bodied users. In the areas of assistive technology and design for disability, human factors must be taken into account during the design. The final user capabilities but also others specific expertise can constitute these human factors.
In the present context, the authors are working with designers who develop products dedicated to play on percussion musical instruments. Musical characteristics are specific expertise that must be integrated to the design of the product. In this article, authors detail the design approaches chosen, the technologies used for manufacturing the system and especially functionalities developed for such a product. They will present how the human factors have influenced the design of the product in the iterative design steps of the UCD methodology.

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1. Introduction

The daily activities in specialized educational school for disabled children are varied: children have not only educational activities, but also cultural and social activities. In the case of musical activities studied here, it is often impossible for children to have access to the musical instrument. The AE2M non-lucrative association (Ergonomic Adaptation of the Musical Material) works mainly with physical disabilities children.

A physical disability is often remedied by the use of assistive devices such as manual or electric wheelchairs [1]. People with these aids generally have difficulty manipulating objects in their environment. The reasons are either, the fact that impaired upper limbs of the user are limited, or discomfort provided by the mobility device [2]. It can be difficult to propose a new interface to the users to perform a task (e.g. playing music). Thus, not only the user but also these personal human factors and environmental factors [3] must be taken into account in the design process.

1.1. Why a multidisciplinary team in the design process?

There are two main groups among system designers for disabled people [4]. The first have well-defined needs and search a technological solution and primarily practical systems, sometimes ignoring the more advanced technologies. The risk here might be to focus on obsolete technology, unusable or too expensive. The second have an innovative technology and researches applications in the field of disabilities. The risk here might be to propose solutions for imaginary or non-priority needs. One solution to circumvent these problems is to create link between these teams of designers, working with a multidisciplinary team.

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The multiple competencies present together will allow development of the system more in correlation with the final user. Engineers from multiple fields and the medical professionals have to work together in these cases. This context imposes strict organization and collaboration that have to be proposed to the complex team.

Researchers have already explored this product development process in [5]. Seventeen design projects involving disabled children, engineering students and special schools were analyzed. Three important aspects emerged from the content analysis. (1) Difficulties identified in the literature arose in the context of this study. (2) Among the difficulties related to the practical barriers of involving disabled children, one new difficulty in particular was identified through the study, i.e. that of partnering with special schools. (3) While existing literature focuses on the practical barriers, the results of this study show that not all difficulties are related to these barriers. In fact, understanding user needs proves to be especially difficult when the product to be designed targets several different disabled users.

This article [5] demonstrates the importance to work not only with engineers and medical professionals, but also with a maximum of people who play a role in the context of use: institution of education, the family, educators, and others disabled children who interact with the considered user.

1.2. Design and disability: an user centered-approach

Design for disabled user is presented as a user centered approach which objective is to improve the usability of the product as a quality factor. Under this designation, the User Centered Design (UCD) methodology has been proposed.

This methodology provides five technical points that the project design must take into account: knowledge of end users (tasks, environments), an active participation of users (needs and requirements), the appropriate repartition of functions between users and technology, an iterative approach to design, the intervention of a multidisciplinary team [6]. The user-centered design cycle is broken down into six steps. This is an iterative process which ends when the design solution meets the requirements of the end user [7].

Coupled with this methodology, different design concepts positioned as user-centered approaches exist [8]. Among them are universal concepts. Ron Mace defined Universal Design as the concept of designing all products and the built environment to be aesthetic and usable to the greatest extent possible by everyone, regardless of their age, ability, or status in life [9]. A set of design principles was specified for this universal approach [10]. Design for All is the European current of Universal Design with an orientation toward Information and Communication Technologies (ICT) [11]. Accessible Design defines accessibility features to meet to enable people with disabilities to access the same spaces and services that everyone [12]. The impact on urban planning and the built environment are many such as sidewalks, automatic doors. The Inclusive Design aims to develop a guide of "best practices" designed for and with designers to meet the needs of disabled people in developing products "general public" [13]. This concept refers to the fact that minorities are taken into account in the design of a product that addresses the greatest number. To resume, the universal concept aim is to design products that are accessible and usable by the largest number of users.

In contrast, there are specialized concepts. Assistive Technology (AT) concept is positioned in the specific needs from a particular medical condition. Users are seen as patients [14]. Adaptable Design's philosophy is to design adaptations by modifying existing standard products to make them usable and accessible [15]. This concept is based on the different approach of modular design of products. It allows the quickly development of new models, to improve existing products as "updates" and to offer customized products by adapting existing models tested [16]. Rehabilitation engineering is an engineering approach by seeking to quantify, measure, and track human performance for providing better adaptations [17]. Ability-based design consists of focusing on ability throughout the design process in an effort to create systems that leverage the full range of human potential [18]. To resume, the aim of specialized concept is to design custom or unique products based on the requirements of the user or a specific medical situation.

The contrast between universal concept and specialized concept is easy to understand. Is it possible to use notions of both concepts to propose an innovative product design process? A first step has been done by the AE2M non-lucrative Association and researchers [19]. In the context of playing acoustic musical instrument, researchers present the design of a universal product which transforms any user environment object to a personalized interface, to play percussion instruments. This shows the possible mix of both approaches to allow a maximum of disabled people to play percussion instruments.

1.3. Customized and personalized products

To develop a product for disabled people is a challenge, not only in terms of product adaptation for customer needs, but in terms of economic viability of products. These two points are intrinsically connected because, sometimes, the level of personalization requirements impedes any try of cost reduction by production volume.

The products of assistive technology have given several benefits to people in difficult situations. However, there are studies that show many problems with AT products abandonments. Concretely, researchers made a deep bibliographic research in the field, to find important product characteristics and several reasons to device abandonments [20]:

- First of all, there is a predisposition to AT acceptance if the person with disabilities had accepted his own limitation problems.
- After that, there are issues about the product itself. In general, the important identified characteristics are cost to purchase and to maintain, durability, reliability, ease of use and transport, safety, efficiency and aesthetics.
- Furthermore, through the field research, they find four factors leading to TA abandonment, namely: change in the needs of the user (by improvement or decline in person's clinical conditions), ease of purchase (in general, products

with more degree of standardization), device performance (attributes such as effectiveness, comfort, usability, e.g.) and consideration of user opinion in the selection process.

From the list, after the decision of all the TA characteristics design, some points are still connectable to the design process. In fact, it is even possible to link the patient's changing needs and the design process. The product can bring improvements to the person, but problems as well.

The most effective way to solve these problems is in the design time. For this, it is required to identify the customer needs and to design the product in order to comply with those. User-centered-design, product customization or personalization, project platform, product configuration, modularization and mass customization are approaches related with this vision. The variety of these approaches and their complementarities could contribute to find the right level to adopt between product variety, that include (in an extreme view) the product personalization, and volume of production, that requires stability in the product design.

Enterprises which want to embrace product customization can adopt the product configurability [21]. That is obtained by combining sets of pre-defined components to generate a variety of products. The authors also define product modularity as a special case of product configurability. The differences between modularity and configurability are in the definition of components options.

Mass Customization (MC) is another management technique for project product that could be used in this situation. Pine (1993) defines it as producing personalized products at similar price than mass production. Mostly application of MC is made through modularized product/service design, flexible processes, and integration between supply chain members [23]. However, there is an important aspect pointed by [24]: there are many works in this field about controlling process variety, cost and delays reductions. Moreover, researchers explain that defining the level of customization which really satisfies the customer is hard to achieve.

Universal concepts and specialized concepts are mainly applied in economic strategies. Thus, the difficulty of manufacturing numerous products for heavy disability users is real. In this article, we not address the complex question of the economical strategy management.

From real needs and thanks to the design and the manufacture of a corresponding product, we show that universal and specialized concepts are not exclusives concepts. Moreover, working all the time with the users increases the chance of acceptance of the final product.

2. Methodology and objectives

From a concrete and real situation of musical instrument no-accessibility, we try to propose tools and primary solutions to manufacture products that could be used by many disabled users. Respecting the UCD principles (five technical points), we developed a product that allows many users to play percussion instruments in different manners.

The first version of the product was proposed by a group of engineering-students in 2006. Since this time, a lot of products development projects have been managed between the AE2M non-lucrative Association, the University of Grenoble, researchers, the musical Conservatory and specialized educational schools for disabled children.

From these years of experience of working together, researchers, paramedical staff, musical teachers and professors have developed specifics competencies in this context. The A2EM association proposes a simple schema that represents the idea of working together for and with the disabled people (Fig. 1.) [25]: the competencies triangle (three professions) of the AE2M Association.

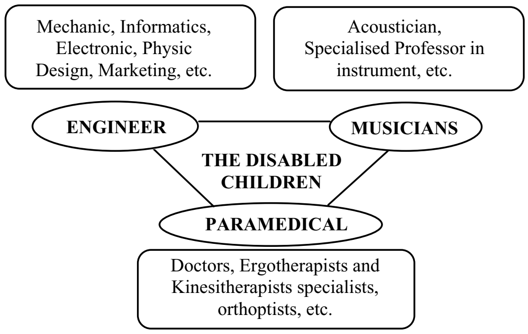

Fig. 1. The competencies triangle for the AE2M Association.

The association use this illustration to communicate and to inform the entire collaborators about the importance to work together, with different competencies to develop the right product.

All along the product development process, designers refer to the UCD methodology. Following are some concrete example of activities.

- Knowledge of end users: a lot of time spend by the engineering-students to observe the final user in situation, with paramedical staff, before beginning the design process
- Active participation of users: in each step of the process, the user and the paramedical team is present, especially during the experiments phase with new prototype.
- Appropriate repartition of functions between users and technology: to make sure that the technology is present to allow the connection with the musical instrument. The decision of playing is taken by the user, the technology chosen allow the disabled people to exploit a maximum of the human capabilities
- Iterative approach to design: fundamentally, the product cannot be developed without this cycle: discussions, design, prototype manufacturing, experiment - observation and analysis, discussions, design modification, etc.
- And intervention of a multidisciplinary team: especially during each meeting or experimentation, at least one representative of each profession.

This methodology we propose and use with engineering student for many years allowed us to propose the following product.

3. Products development

The electromechanical drumstick (short name of the system: MEM) enables to hit on a drum using a lever. The lever is generated with a spin and a force produced by the raise of an electromagnet (EM in Fig. 2.) and a spring (S in Fig. 2.) permitting the return in initial position (see Fig. 2).

The electromagnet is a pushing type constituted of a coil and an axis. When activated, the axis is raised and leads the drumstick (DS in Fig. 2.) which rotates around its pin. A little spring is located between the end of the coil and the axis to keep them from "sticking" together. When not activated, the axis of the electromagnet is stopped by the housing and thus keeps a constant course.

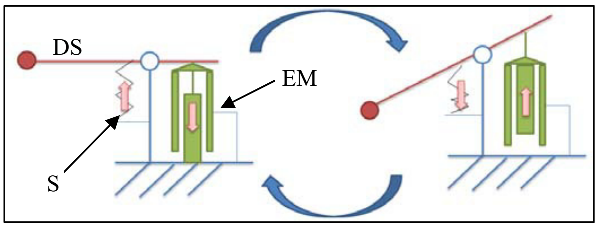

Fig. 2. Illustration of the lever (EM: electromagnet; S: spring; DS: drumstick).

The pin is created with a specially designed piece using 3D-printing (FDM) called "pin part" (in red, Fig. 3), a screw with smooth body and the housing of this system (in blue, Fig. 3.). The screw is fastened on the housing, leaving the "pin part" freely rotatable around the smooth part of the screw. The drumstick is held on this "pin part" and is located a bit higher than the centre of the pin. The drumstick is maintained in position in this "pin part" by the help of another screw (M4*10mm). It is recommended to place the drumstick to have a length of 210 mm between its head and the centre of the pin.

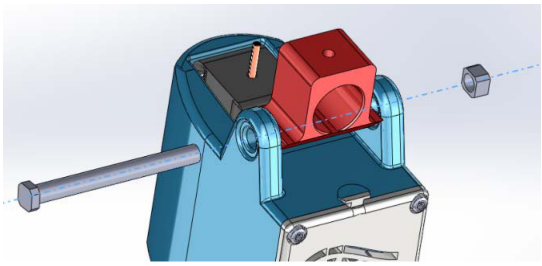

Fig. 3. Pin's assembly.

To maintain the drumstick in contact with the axis of the electromagnet when it is in its lower position, a spring is placed just after the pin (Fig. 1.) on an extrusion visible on Fig. 3.

The electromagnet is positioned, relatively to the centre of pin, at 40 mm and 10 mm under this one. This constant position is enabled by a housing produced with 3D-printing (FDM), the electromagnet being fastened on this housing.

This housing and "pin part" can be easily created in limited edition with 3D-printing technologies. There are several processes to make those parts. The availability of multiple manufactured processes is an enormous advantage in this kind of project. It is possible to use the more effective one depending of the using case. All of them allow the manufacture of a custom component that is exactly compatible with our area of product development. The following section shows advantages and drawbacks of each of them.

- Classical machining (Fig. 4.): a long and expensive process Z-printer (Fig. 5.): this manufacture process consists on solidify plaster powder, layer by layer, using binder. All shapes are possible but the final product has little resistance, which is the not acceptable for the MEM. This manufacture process is ideal for prototyping and discussing a new solution but the piece is generally not functional.

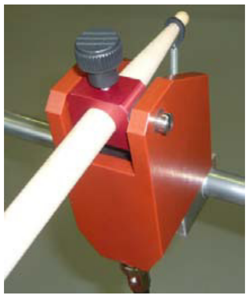

Fig. 4. Machined housing and "pin part"

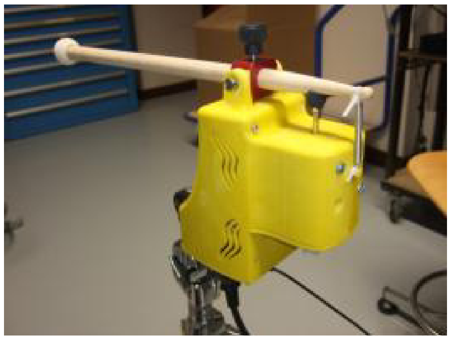

Fig. 5. z-printed housing

- Z-builder (Fig. 6.): this manufacture process consists on solidify, layer by layer, a liquid photopolymer using a digital light processor projector. All shapes are possible, but supports are necessary. An object produces with this technology is pressure resistance but with little resilience thus still unusable for the MEM.
- Stratoconception: the concept is to machine slide material and to stick those slides together, with the help of positioning insert, to recreate the final product. This process is not coherent for our housing with trick walls.
- Fused deposition modelling (FDM): a plastic string (PLA, ABS…) is heated and deposed with the desired shape, constructing the object layer by layer.
  - Low-cost type FDM (Fig. 7.): very cheap, but slow. A lot of shapes are possible considering support. Those are made of the same material than the piece hence will most likely leave marks.

- Professional FDM: more expensive but more precise and more reliable. Supports are soluble at sodium. This is considered the best technology for the MEM

Fig. 6. example of z-builder piece

Fig. 7. MEM made with Rep/Rap

In this housing is also located an electronic card which control the electromagnet. It takes in entrance a standard PC alimentation which powers the electronic card and the electromagnet, and a switch which allows the on/off (Fig. 8.)

This card is programmed to activate the electromagnet in ten different modes. These modes have been defined with the paramedical staff and the musical teachers. Their objectives are to allow the play with the drum for people with different kind of disabilities.

- Mode 0 or « Normal mode »: a press on the user's switch activates the electromagnet and is deactivated only when the user releases the contactor. Holding the switch more than 6s can damage the electromagnet thus a protection is installed on the electronic card: the electromagnet is automatically deactivated after 5s.
- Mode 1 or « Rebound mode»: even if the switch is press-on a long time, the electromagnet is deactivated almost instantly after the hit.
- Mode 2 or « Reversed Mode»: the electromagnet is activated by the release of the user's switch.
- Mode 3 or «Burst Mode»: a long press on the switch activates a burst of hit at the frequency defined by a tempo.
- Mode 4 to 9: a press on the user's switch activates the electromagnet and makes it play, one time, the sequence associated.

Mode 3 to 9 can be played with specific tempo. The electronic card enables 10 tempos: =60 then 75, 90, 105, 120, 135, 150, 165, 180 and 200 (defined by the musical teacher).

To select the desired mode and tempo, the card is equipped with 2 push-buttons and associated screens (every press on the switch increment the screen). Finally this card carries three LEDs which permit respectively to know the proper functioning of the electromagnet, the user's switch and the alimentation (cf. figure 3).The system is held in position on a cymbal stand with a pressure screw. The cymbal stand can then be settled in the desired position

4. Discussions

In this project which began many years ago, the AE2M association has developed many prototypes. In the last version proposed, the designers insist on the capability to meet the different disabled's requirements.

At first, the choice of the human interface can be made by the user itself. The product is designed to be connected to a standard connectivity, currently a mini-jack 3,5mm. Normally, it allows the user to keep its preferred personal interface.

Secondly, the technical choices of the product allow its adaptation to a maximum kind of disabilities encountered during the eight years of experience. The description of the four first modes in section three justifies this adaptation.

At the end, the others modes (four to nine) allow another kind of adaptation to the type of music the musical teacher proposes.

The claim of the paper is first of all the proposition of a product and its personalization possibilities. But the second objective is to explain technological and methodological means used to build this kind of system. For the major part of the future projects, the association will follow the same demarche.

5. Conclusion

The context of this study allows us to contribute to the design methodology research area especially by domains of Human factor in Design and Customized and Design product Development.

Not only we really contribute to the well-being and social integration of children with disability by manufacturing this kind of product, but also we need to think about a better product design process to better adapt the product to the market.

In the precise situation developed in the article, the complex housing manufactured in rapid prototyping is one key of the complete system. For a lower cost of the complex system, it is important to find the right 3D-manufacture process adapted to the situation. In 2006, the complex housing alone cost 280euros. Nowadays, the new 3D-manufacture process allows a cost production of the complete system of 245euros.

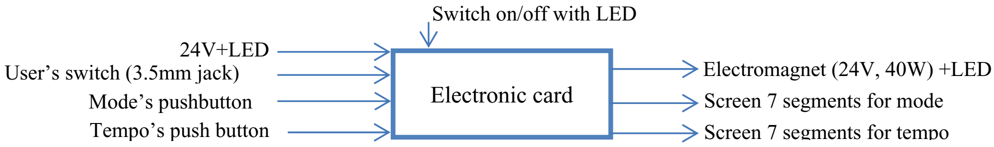

Fig. 8. Electronic card

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