Integrating the human factors characterization of disabled users in a design method. Application to an interface for playing acoustic music

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Abstract

Users and uses inclusion in product design remains a challenge, especially when their characterization is very specific, which is the case with disabled persons. Many design methodologies integrating user exist, for example, User-Centered Design (UCD). The application of these methodologies results in custom product designs, but they haven't objective the motor activities characterization of stakeholders: people with disabilities. Our ambition is to characterize and model the motor specificities of these future users during the design process to adapt the man-machine interfaces to these motor performances. In this paper, we propose an adaptation of the UCD design process by integrating theoretical models and technological tools of motion capture. In conclusion an in response to identified needs of AE2M project (*E*rgonomic *A*daptation of the *M*usical *M*aterial), we present an application of our approach in this context.

Key words

Design, user-centered design, disabled people, man-machine interaction, motion capture

1. Introduction

Traditionally, designers create products or interfaces for able-bodied users, assumed to have normal motor skills **(Keates et al., 2000)**. Atypical users, including people with disabilities remain outside of these skills and capabilities standards, and are forced to adapt with existing systems, using technical aids. Unfortunately, these technologies are impractical for people with temporary impairments and not adapted to users whose abilities change over time. The data, detailed in a research report conducted by INSEE (*F*rance's *N*ational *I*nstitute of *S*tatistics and *E*conomic *S*tudies), show a significant need of assistance in handling (only 35.3% satisfaction for remote handling) **(Colle et al., 2007)**. Nevertheless, these aids are often abandoned because of their price and use complexity. WHO (World Health Organization) has developed a world report

on disability in 2011 **(WHO, 2011)**. It shows an increase of the population living with some forms of disabilities (10% in 1970s to 15% in 2011) due to the increasing aging population, chronic diseases and poverty. The report offers nine recommendations for the activities prospects with disabled people. The fourth explains the need to involve users in these future activities. Thus, the minimal integration of these users through the design process is questioned.

The involve of users in the design process was studied through universal concepts **(Laroche, B, 2004)**, specialized concepts **(Clarkson et al., 2003)** and user-centered design **(ISO UCD, 2010)**. Literature shows not only a great mobilization but also an important utility of user-centered design in the design of technical aids **(Magnier et al., 2010)**. Despite this, designers rarely use in the UCD design process, additional tools from other scientific fields.

Since 2007, the AE2M project works on man-machine interface production to provide access to instrumental music for users with disabilities, with the same autonomy level as non-disabled **(AE2M, 2012)**. It consists in produce acoustic sounds and to ensure which disabled physical children can voluntarily himself act on the instrument. A specific project realized is an electromechanical system to allow a strike of the mallet on percussion instruments (Figure 1). The user activates the system by means of accessories (push button, pressure effort ...).

Fig.1 using the electromechanical mallet in music game

The prototypes dissemination at paramedical professionals and teachers musicians has allowed the realization of many in situ experiments **(Magnier et al., 2012)**. The physical abilities knowledge of users has been identified as a crucial point for designers. Thus, not only user motor specificities, but also their progressions over time are central parameters on which the design team needs to focus. The AE2M project led us to the following question: How to integrate the physical specificities characterization of disabled users in the design process?

To answer this question, our approach is based on the user's knowledge relative to the disability, the state of the art theoretical models and the technology for the motor skills analysis.

Section 2 presents the future users from disability definition and the various professions which surround the AE2M project. Following this identification, section 3 offers an alteration of User-Centered Design including the analysis of motor skills. We define a protocol corresponding to steps to characterize the user physical specificities. In section 4, we present our approach based on the needs of the AE2M project. The goal is to use our library of tools to provide a Gestures / Music adapted interaction. In section 5, we show the tool based on the 3D depth Kinect sensor and the first results obtained for physical specificities characterization. This article finishes with a conclusion of preliminary works and research perspectives.

2. The stakeholders

In this section, we offer a stakeholders presentation from the disability definition proposed by ICF (*I*nternational *C*lassification of *F*unctioning, *D*isability and *H*ealth, Figure 2) **(ICF, 2001)**.

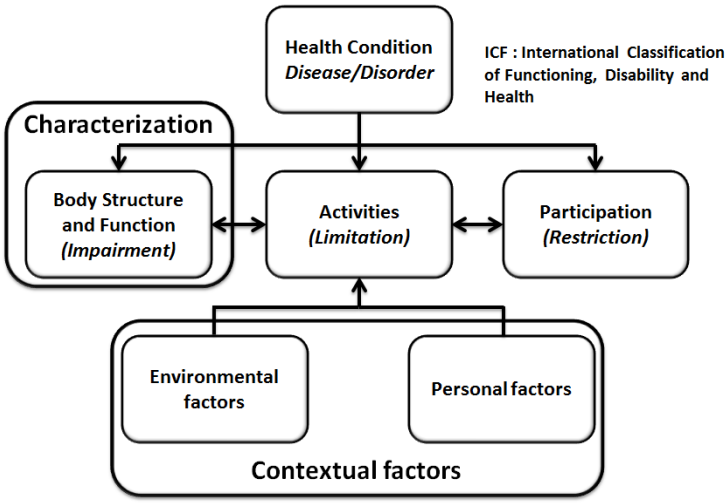

Fig.2 The International Classification of Functioning, Disability and Health definition

It highlights the environmental factors influence on disability, which is the main difference from its previous version, *I*nternational *C*lassification of *I*mpairments, *D*isabilities, and *H*andicaps (ICIDH). Disability is surrounded by three terms related to each other: impairment, activity limitations, and participation restrictions. Impairments refer to modifications of body functions or anatomical structures, such as paralysis. Activity Limitations are difficulties an individual may experience in them (walking, eating, etc...). Participation restrictions are problems an individual may meet to participate in a situation of daily life, such as transportation inaccessibility. Disability therefore results from the interaction between a person with health problems and contextual factors (personal and environmental).

Our design methodology should enable the product manufacturing or adaptations to help disabled people to enjoy daily life activities (e.g. playing music at concert). We must take into

account the user impairments (by the physical specificities characterization) and his contextual factors (by discussions with user himself and his circle) in the design process.

3. An alteration of User-Centered Design

We offer in this section our reflection on an adaptation of user-centered design with attention to the physical specificities of people with disabilities.

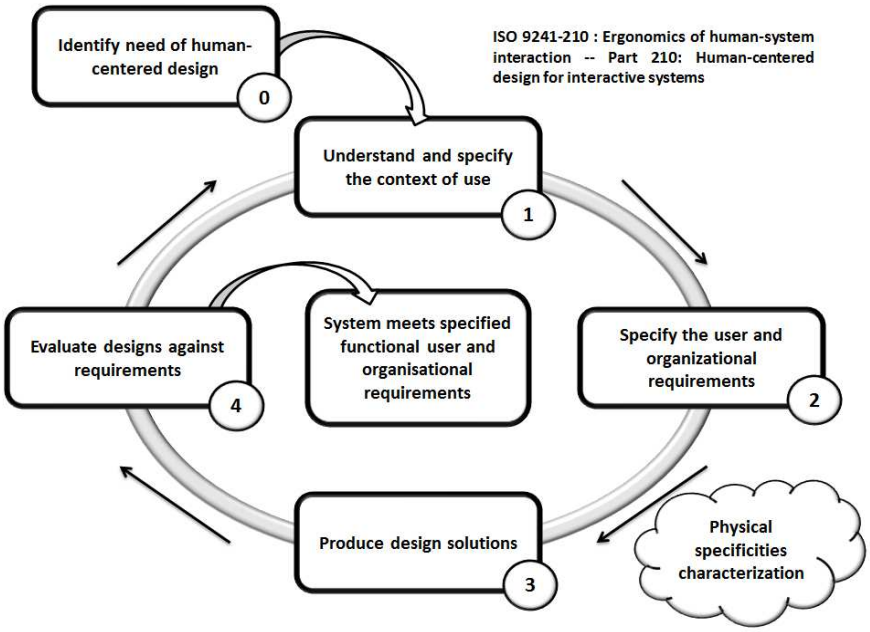

Fig.3 ISO 9241-210 UCD Process

The physical specificities characterization starts after specifying the requirements of user and organization for the user contextual factors. We identify and propose four main steps which precise the sub-procedure to apply for the characterization of the physical specificities.

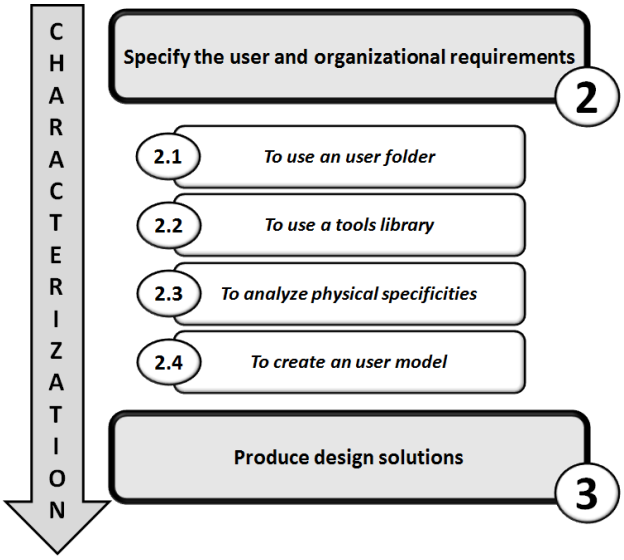

Fig.4 Steps for physical specificities characterization

First, it’s necessary to define a user folder to identify globally from these physical abilities. Then, we propose to choose the best tool suited to the user based on his folder. For this choice, our proposal is to combine theoretical models and technological means to create a library of tools. The next step is the analysis of the physical specificities. It will run, depending on the tools selected to measure in our library, through innovative and dynamic interfaces. The results are stored for processing in the last step. They will define a "user model" of these motor skills. This model will provide useful information for the continuation of User-centered design: generate concepts solutions.

4. Application

We have previously defined our approach to characterize the physical specificities. We apply it to design a new man-machine interface adapted to the motor skills of disabled users.

4.1. To use an user folder

Scales have been developed to objectively evaluate performance skills. They are defined by several criteria: age (infants **(van Haastert et al., 2006)**, elderly **(Schepens et al., 2009)**), pathology (BMI **(Girardot and Bérard, 2005)**, muscle atrophy **(Nelson et al., 2006)**), the number of task being performed (thirty two items **(Bérard et al., 2006)**, twenty items **(De Lattre et al., 2011)**), goal (identify the delay in motor **(Stokes et al., 1990)**, functions of the upper limbs **(Lang et al., 2006)**). We based on these criteria to propose a methodology with the aim to prepare the user folder. It will contain the results of the user to perform "n" tasks using his motor skills. The tasks will be selected based on their number "i". Measurements start at i = 1. The user performs a task T(i). It's analyzed A(i) from a scale. The score is relating to the performance of the activity.

For example:

- A (i) = 0, the user doesn’t realize the task at hand
- A (i) = 1, the user performs the task with assistance
- A (i) = 2, the user performs the task alone, unspecified or after a certain time
- A (i) = 3, the user has correctly performed the task alone

We now have the R(i) result in the form of a matrix (n rows and two columns).

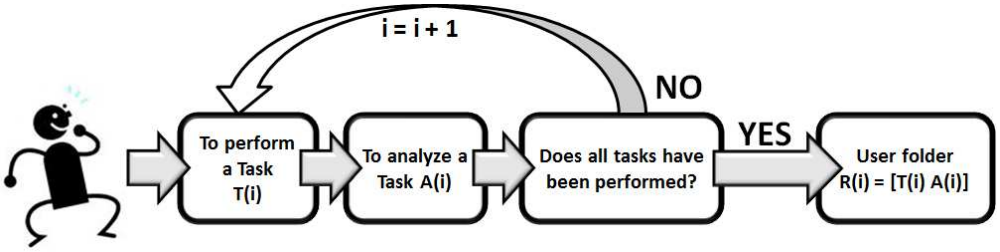

Fig.5 Method to fill in the user folder

4.2. To use a tools library

A man-machine system is composed of two parts: the man with biological, psychological, social characteristics, and the machine a technological system. There is an interaction between these two parts **(Johannsen, 1982)**. We will define this interaction based on a selection of motion capture technologies adapted to the use conditions. We wish to analyze the user behavior in front of an interface and the motions dynamics. We generated our tool library as follows.

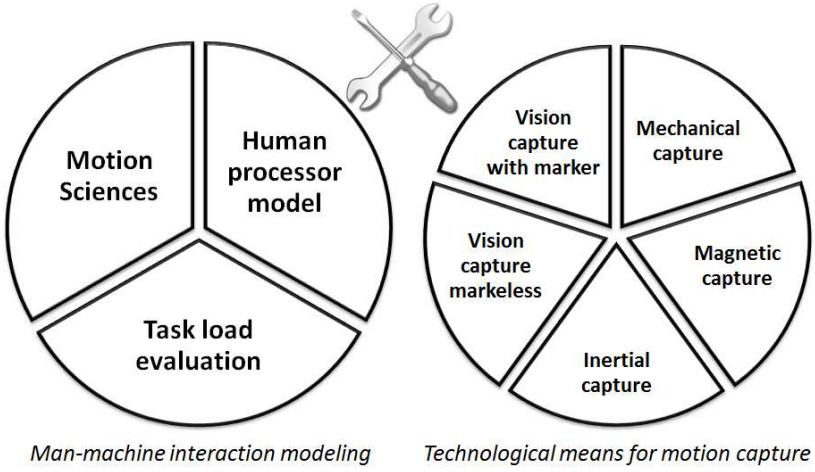

Fig.6 Tools library

We selected theoretical models for the man-machine interaction modeling and technological means for motion capture.

4.2.1. Theoretical models

We take an interest in this part at theoretical models studying man-machine interaction. Variability of uses and users needed to characterize the motor behavior of the user on the system to optimize it according to its capabilities. So we want to describe, model and predict his actions on the interface. There are two main models in man-machine interaction. *Descriptive models* describe the interface behavior in front of user. *Predictive models* represent the systems behavior in the form of laws or mathematical equations to account for the time to complete a task. They

therefore involve the user performances. **(Vella, 2008)** proposes a classification of these models based on the continuum defined by MacKenzie **(MacKenzie, 2003)**.

To characterize the physical specificities, the principles of science motion can complement these theoretical models. We can divide them into two categories: the movement dynamics (speed, acceleration, range of motion) and the movement neuroscience **(Wolpert and Ghahramani, 2000)**. The latter analyzes the transformation of sensory signals at motor commands within the central nervous system (CNS: Central Nervous System). It is often used to optimize the behavior models **(Todorov, 2004)** or the assistive robot design **(Meary and Baud-Bovy, 2009)**.

We can compare interfaces by analyzing, after use, the user workload. NASA developed the TLX **(Hart and Stavenland, 1988)** method which is now one of the methods of subjective assessment of mental workload the most used in ergonomics **(INRS, 2009)**. It is the user that determines the results of this method according to six criteria: mental activity, physical activity, time pressure, performance, frustration and effort.

4.2.2. Technological means for motion capture

According to the literature and professionals, there are four main modes of motion capture: electromechanical systems, magnetic systems, inertial systems and optical systems.

The electromechanical systems are exoskeletons built around the element to be detected and each joint is provided with a potentiometer that measures the orientation of the member in real time **(Gan Lu et al., 2009)**.

The magnetic systems operate as follows: a transmitter generates a magnetic field modulated at low frequency. To define the global coordinate system, its antennas are placed orthogonally with respect to the measurement plane. Receivers determine their positions and orientations relative to the transmitter **(Hagemeister et al.)(Ganapathy et al., 2010)**.

By a technology combination, for example accelerometer and gyroscope, inertial systems are able to calculate the speed, direction and gravitational forces applied to the object and transmitting them to a remote system. Their primary function is to deliver a measure of orientation, not position **(Jallon et al., 2009)**.

The optical capture is based on the synchronized views of one or more cameras. It can be done without markers (with methods using image processing algorithms) or markers (passive or active) on the subject or the object to be detected **(VICON, 2012)**.

4.3. To analyze the physical specificities

The physical specificities analysis is executed through a Graphic User Interface (GUI) from tools of our library. The choice of interface design and type of activities are very important. Indeed, it's the activities performed during the measurements that will determine the motivation of the user and especially the relevance of the retrieved data. They will be chosen based on expectations, user and organizational context requirements.

4.4. To create an user model

The user model will allow designers to produce custom solutions, depending on motor skills. It will be important to formalize the data formatting. For example, if we choose to adapt the interface from a CAD model, the unit used is the meter; if we focus on the adaptation of graphical user interfaces, the unit is the pixel.

5. A low-cost tool to characterize motions with Kinect

For motion capture tools, the most important criterion in addition to accuracy is compact and non-intrusive / invasive. The equipment must be easy to install and should not "harness" the user. Optical capture without markers meets these criteria. Thus, we develop a measurement tool from an optical capture without markers. We currently use the Microsoft Kinect for retrieving a digital three-dimensional skeleton of the user. This proposed tool allows: to view Kinect videos stream and the digital skeleton, to use theoretical models from our library of tools to characterize the movement (position, speed, joint angle...) and to conduct a data backup for a posteriori analysis (Figure 7).

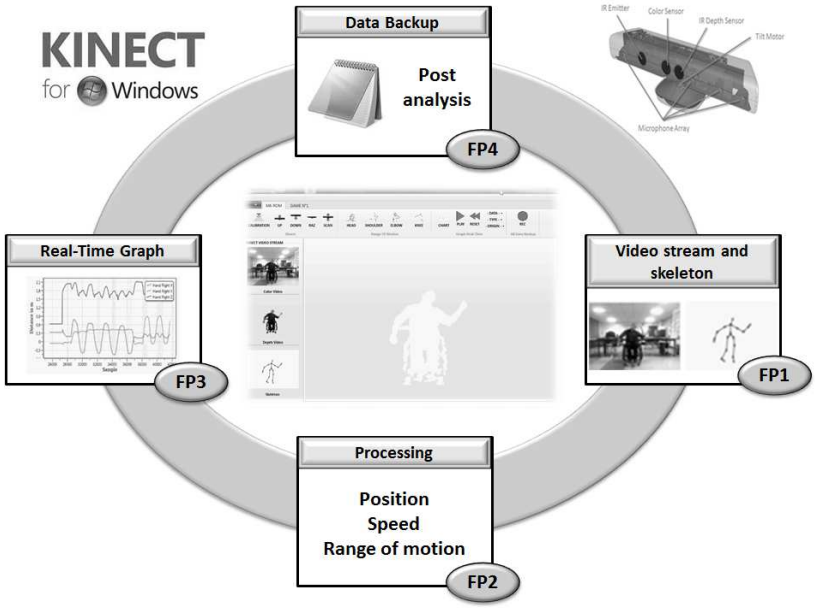

Fig.7 Principle functions of our tool based on Kinect

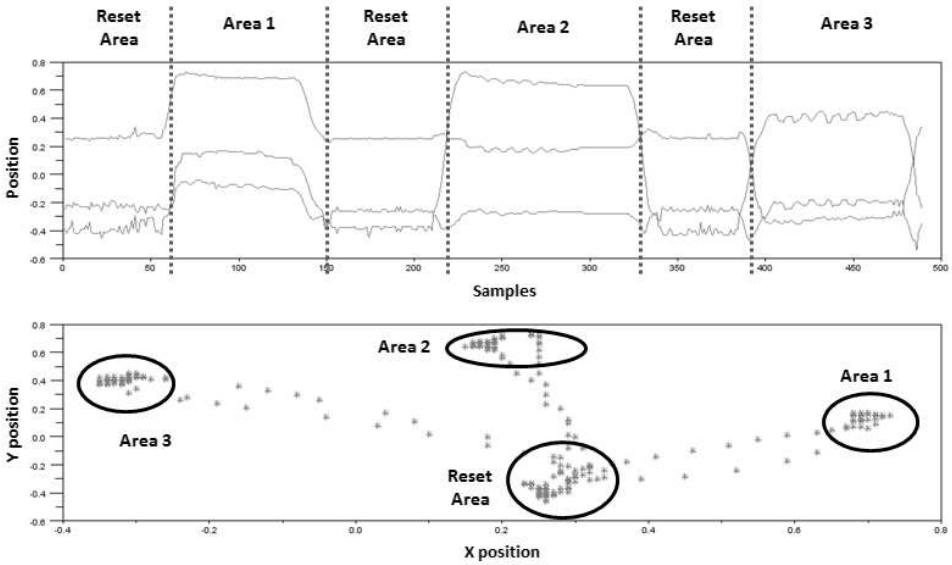

Fig. 8 a- x, y and z positions of the user right hand during 500 samples;
b – positions of the three working areas and the reset area in the x-y plan

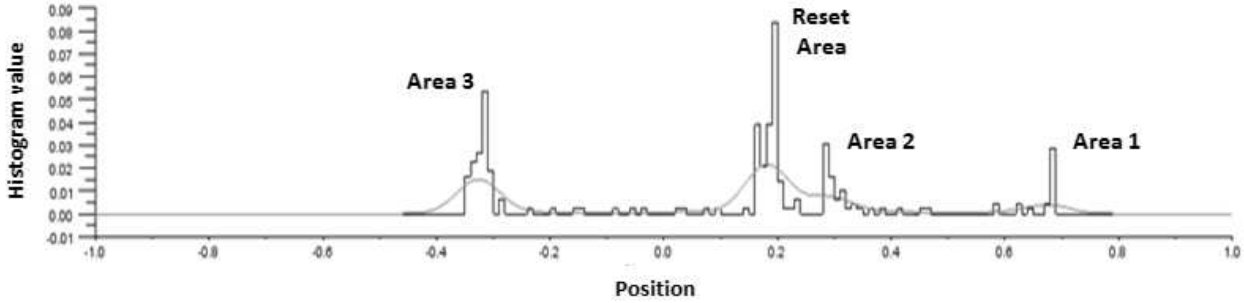

Fig.9 Histogram of x-axis hand right position

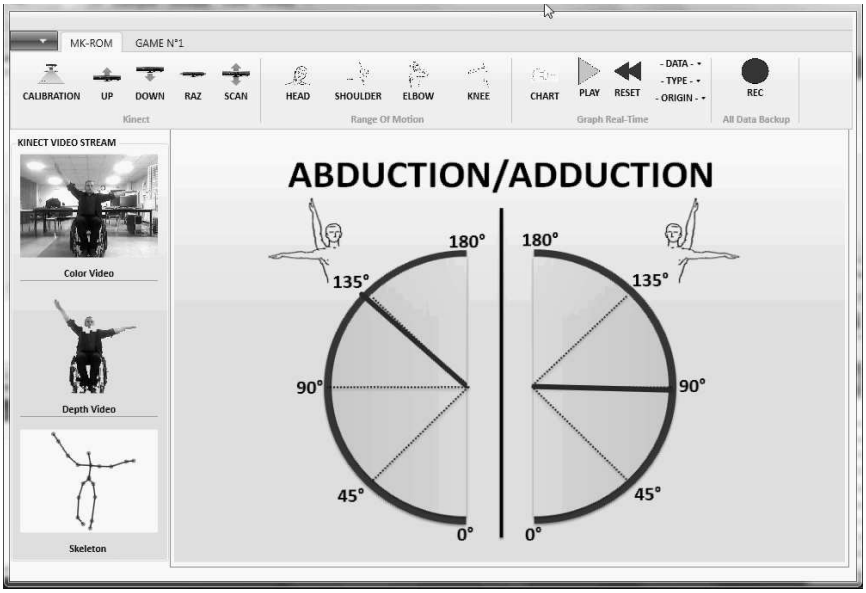

Fig.10 Real-time measure of shoulder abduction/adduction

Figures 8 and 9 present a sample of a posteriori analysis. They show the user's accessible area by manipulating the Kinect. During the movement activity, the user moves only his right hand. Thus, he defines itself three "working areas" and one "rest area" in front of the Kinect tool. Figure 8a shows the timeline positions of the user right hand during 500 samples (approximately 30 seconds). Figure 8b shows the positions of the three working areas and the reset area in the x-y plan. In this figure, one point is marked at each second. Figure 9 gives a histogram of the hand right position in the x-axis. This graph is obtained after posteriori analysis. It is then possible to find and register regions defined by the user. Figure 10 shows real-time analyses of shoulder abduction/adduction using motions sciences theoretical models of our tools library.

6. Discussion

We applied our approach to integrate tools to characterize the physical specificities of disabilities' users. The user folder is drawn from existing scales to objectively analyze the motor skills of people with disabilities. They are mostly used by doctors in hospitals or in special schools by therapists. To what extent the designer can use these methods in a design activity? We will take a leaf out of its tests for the first stage of our design methodology (Fig.4 2.1).

For the generation of the tool library (Fig.4 2.2), we need theoretical models to analyze the behavior of users on the man-machine interface. This study is useful to enrich our knowledge of the specific characterizations drive user behavior on an interface before. In addition to these models, we have developed a tool based on markerless optical tracking with the 3D depth sensor Kinect. We arrive to analyze the accessible area of disabled user and the joint range of motion. The next step will be to generate automatically a GUI (Graphic User Interface) from his physical abilities to realize motions.

7. Conclusion and perspective work

Our objective is not only to design and manufacture custom man-machine interface for users with disabilities, but also to know their characteristics accurately. Thus, our specific contribution compared to current methodologies is to propose a model of the user. Our adaptation of the UCD design process incorporates both the overall knowledge of the user in relation to disability and characterization of the physical specificities. We have integrated tools from other areas of product design. We propose methods for their use throughout the design process. The different perspectives and applications are defined by the AE2M association needs. We will use our tools

library to obtain a physical specificities model of disabled children for a musical play. We will supply this model at engineers to produce prototypes of interface for the future users.

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