DHM to investigate product ergonomics and visual representation of results

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Abstract

The simulation of human-product interaction belongs to the mega trend of Virtualization, combining virtual products and human modeling. Nowadays, either industrial products or commodities are supposed to be validated in many ways including ergonomic issues. Actually, the interaction with the different people that may have to deal with the product is crucial to provide an efficient and robust outcome. Beside final user actions, maintaining, assembling, installing or performing other activities related to products life cycle require a human intervention and, thus, a proper ergonomic design and check is encouraged.
In this work we show an investigation method based on digital human models to evaluate product usability related to ergonomics. A proper test campaign is defined to reproduce in details the most challenging circumstances taking into account several system variables such as product configuration (e.g., different geometries or dimensions) as well as different human features (e.g., size, posture, position, orientation) beside eventual environmental condition that may influence the way the task is.
The paper shows the implementation of the method trough a case study in the domain of commercial refrigeration. A freezer display unit of the kind normally used in supermarkets and groceries is investigated taking into account the case of use of a customer opening the door and picking up a product. Visibility and reachability issues are investigated for any point on a grid on each shelf paying particular attention to interference between the customer and freezer components such as doors and shelves. The results of the test performed are collected in visual maps overlapped each to the referring shelf of the display unit so that the design team can easily manage all data with a few structured pictures.

Keywords: Digital Human Model, accessibility, visibility.

1. Introduction

Virtual ergonomics tools permit engineers to identify multiple and complex problems involved in human–product interactions in the early stages of design process.
This work shows a method allowing to analyze both reachability and visibility on commercial products and to obtain numeric results as well as graphical representation on the product itself. The method relies on a parametric definition of the actor, of the product geometry and of the environment allowing a fast and exhaustive exploration.
The use of a graphical way of showing results is the key factor for the fast identification of any potential problems and boosts-up the communication among designers and with not technical people.
This paper presents at first a brief overview of Digital Human Modeling tools, then a description of the method proposed followed by the case studies and the gathered results. At last a critical discussion about results and method concludes the paper.

2. Previous work

DHMs are used in several industrial contexts to address safety issues, to design better products or to improve existing design methods. Ergonomic aspects can be introduced within the method of Design for Assembly or Design for Manufacturing (Regazzoni & Rizzi, 2014). For instance, in case of maintenance activities the use of DHM can provide some indication to reduce work related musculoskeletal disorder normally related to repetitive or uncomfortable tasks. The focus of the present work is to consider customer's interaction with a generic product combing the use of DHM and parametric CAD programs to provide the technicians with an interactive method of evaluating ergonomics in terms of accessibility and visibility of different design variants.
Concerning human models, various tools of different complexity can be found on the market or in academia and many research activities are under development to fulfill the requirements coming from different industrial sectors to solve specific

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problems. We have grouped them into four main categories (Figure 1) (Duffy, 2007):

- Virtual human/actors for entertainment, used to populate scenes for movies and videogames production. Virtual crowd simulators (Thalmann Et al., 2009), belonging to this group, can be also adopted to simulate emergency situations and for training purpose.
- Mannequins for Clothing (Volino, Et al., 2008) (S.S.M. Et al., 2011) used to create virtual catwalks, virtual catalogues, and virtual try-on show rooms and to design garments.
- Virtual humans for ergonomic analysis, three-dimensional models of the human body, used to study human-machine interaction that can be used to define complex scenes, analyze postures, simulate tasks and optimize working environments.
- Detailed biomechanical models (Abdel-Malek, Et al. 2009) (www.lifemodeler.com), usually more complex than previous ones, structured into three distinct components: the skeleton with deformable elements and joints, skin and muscle tissues, tendons and ligaments. Applications concern ergonomics analysis, medical equipment, study of safety in transport, and human performance during sports activities, etc.

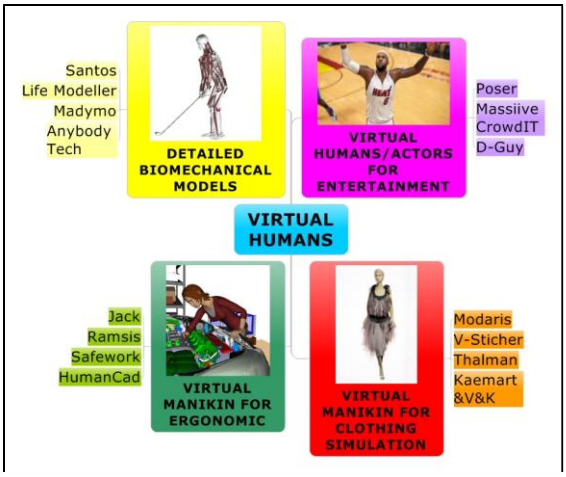


Figure 1 - Digital human classification and tools

As said, according to specific needs digital humans and related tools can be used in various applicative domains such as automotive (Colombo Et al., 2005) (Mueller Et al., 2009), aeronautics (Green Et al. 2011) (Dantas Alves Silva, Et al. 2007), bioengineering and medicine (Bucca Et al., 2009) (Xu, 2005), videogames, movies, education and training.

In this paper we consider a tool belonging to the Virtual humans for ergonomic category that can be profitably used along the product development process to show and analyze how humans should act in various situations and execute required tasks but also to predict the impact of their actions on musculoskeletal apparatus (Naumanm & Roetting, 2007).

In previous works we have experienced the use of Virtual Humans in ergonomic design of supermarket refrigerated display units in loading equipment for commercial refrigerators and in the design for maintenance of compressor units (Colombo, Et al., 2010),.

Also if the product we examined, i.e. the display unit, is not complex there are different challenges to face when considering maintenance workers, shop operators and customers buying products placed on the shelves. Actually, each category has different requirements and performs different tasks with the display unit. For instance when considering the buying phase the common experience is that a customer walk in the supermarket lane, watches the shelves, individuates what s/he need and then grab it and put it in the shopping cart. There are some implications to this sequence of events: the first is that the customer has to clearly see what is available on the shelves and s/he will prefer the better placed products; the second implication is that s/he has to grab it easily otherwise s/he will change product or will be discouraged to buy it.

3. Methods and Tools

We propose a method based on DHM and a parametric CAD software in order to evaluate in details accessibility and visibility of products, generating results that are both numerical and graphical for an easy comprehension and usability.

Human modeling tools are used in the traditional way to simulate the person physically interacting with the product and the environment. This allows gathering both numeric and graphical results concerning accessibility and visibility of products.

Besides, the CAD tool permits to manage in a parametric way both product geometry and scene configuration. Thus, the results obtained can be shown directly on the products analyzed by using color maps overlapped to the 3D model (Figure 2).

3.1. Case study

The case studies refer to vertical refrigerated display units being used by customers.

To evaluate the design of a display unit three main phases involved in customer-display unit interaction have been defined:

1. Visibility from the middle of the supermarket lane.
2. Visibility standing close to the display unit.
3. Reachability of products on each shelf.

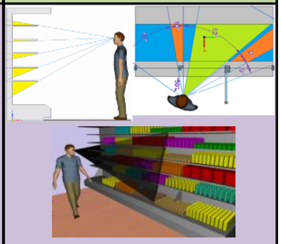
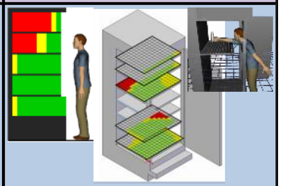
OUTPUT	TOOLS	METHOD
Visibility data	CAD + DHM	
Reachability/ Accessibility data	DHM	

Figure 2 - Graphical description of method used.

All these aspects are related to the buying experience. Visibility from the center of the supermarket lane is crucial as the first approach of the customer to goods. Visibility standing near is measured in the position that is typical of a person that is going to open the door of the low temperature fridge. Reachability of each shelf gives the indication of the ideal length and position of each shelf to maximize accessibility and of the effort of the customer to grab the goods. All these aspects defined and measured can give significant insights to engineers for a better product design involving aspects such as shelves position, inclination and lighting.
Our method will be applied to two specific products:

- Case 1: high temperature (0-4 °C) open display unit (without doors) (Figure 3a);
- Case 2: low temperature freezer (-25 °C) closed display unit (with doors) (Figure 3b).

(a) (b)

Figure 3 – Refrigerated display units under investigation

In the first case study we assessed the reachability of each shelf and the visibility from the lane.
In the second case study we considered the influence of frames and doors when taking a product out of the shelf and the visibility both from the lane and from a close position.

3.2. Reachability tests

To evaluate reachability and visibility in the first case study and reachability in the second one we used the DHM tool Siemens Jack 7.0.
Each display unit has been tested with six human models sizing from the 5th percentile female to the 95th percentile male, selected with the staff of the display unit manufacturer (Table 1).

Table 1 - Human sizes considered.

SUBJECT	HEIGHT (cm)	WEIGHT (Kg)
95 th male - M95	187	101
75 th male - M75	184	91
50 th male - M50	175	79
50 th female - F50	163	63
25 th female - F25	158	56
5 th female - F5	153	51

Different customers' postures have been simulated. To better understand customers' habits we observed a group of them during a normal shopping experience and we defined the most recurrent postures and actions. We record also unacceptable behaviors, such as stepping on the first shelf to reach the highest (upper left image in Figure 2).

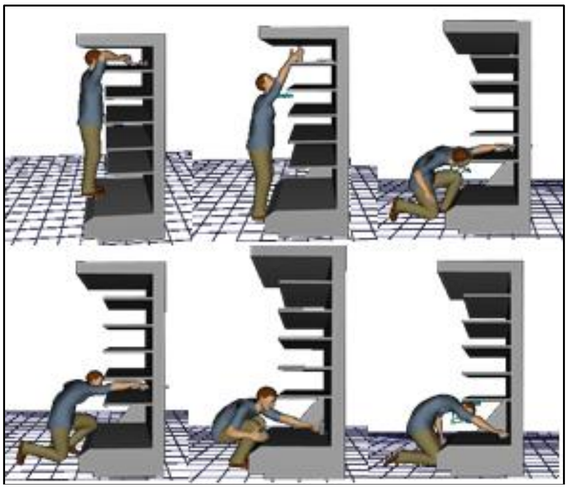


Figure 2 - Posture assumed for reachability analysis.

Reachability has been evaluated measuring the distance from the hand of the human to the bottom of each shelf.
A single indicator for the reachability of each shelf has been defined weighting the results gathered for each virtual model.
For case study 2 we analyzed the accessibility of each shelf verifying the eventual occurrence of interference between customer's hands, arms or head and structure of the display unit. To do this we build a 3D model of the display unit and then defined on each shelf a grid of 50x50 mm and for each point we simulate the position assumed

(14x11 on each of 5 shelves) by the customer to grab a product. For any configuration assumed we observed the relative position between body and frame and in case of contact, or distance minor of 50 mm, we record which body parts and structure parts were interested.

We overlapped the results on the grid for each shelf using a simple color map (Figure 5) in which:

- Red means there is a contact between consumer and display unit.
- Yellow means the customer is close (d<50 mm) to the display unit;
- Green means there is no contact.

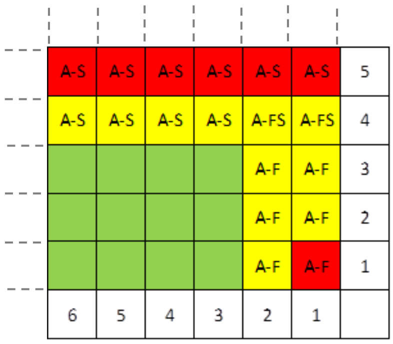


Figure 3 - Fragment of a color map on the accessibility of a shelf.

Any red or yellow cell has an annotation describing which body parts and structure parts are involved. As shown in Figure 3 the first letter indicates the body parts (i.e. A is for arm, H is for head) and second letter is for structure parts (i.e. S is for shelf and F is for frame).

For each human size and each shelf considered we defined a set of standard postures: standing, kneeling on one knee (using the same hand of the knee on the ground or the opposite), squat and two knees on the ground. For each of these postures were considered also different orientation relative to display unit (Figure 4).

3.3. Visibility tests

Visibility tests refer to the phase of product searching while the customer is walking on the supermarket lane, and product selection when the customer has found the right display unit.

For instance in Figure 5 shows the vision cone of a 50^{th} man walking in the middle of the lane.

In order to evaluate visibility from the lane we used a vertical cross section of the display unit.

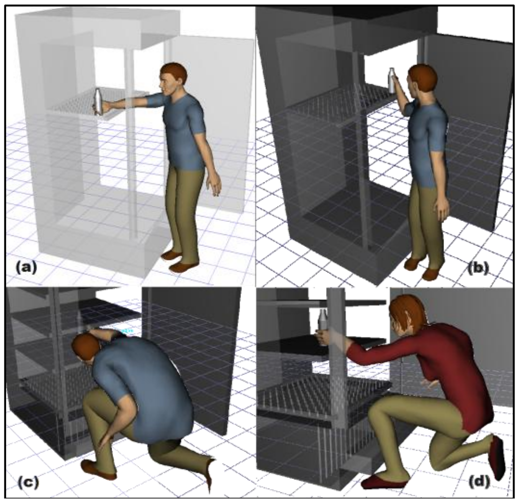


Figure 4 - Sample postures for reachability analysis: (a) standing and 45° rotated on the left; (b) standing and 90° rotated on the left; (c) kneeling on one knee and using opposite hand; (d) kneeling and using homolog hand.

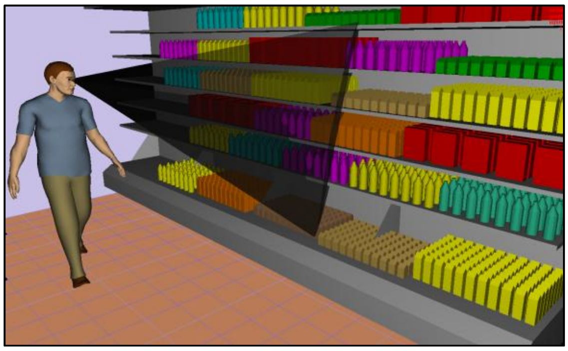


Figure 5 - Visibility when walking through the lane, vision cone highlighted.

According to the configuration shown in Figure 6 we used different distances of the human from the open door-less display unit (varying from 1 to 2 meters) and depending on human percentile we changed the vertical position of the viewpoint.

The same approach has been used also to evaluate visibility at closer distance (between 150 and 500 mm) occurring when dealing with a display unit with doors. Actually once the door is open the customer is obliged to stand closer. Figure 9 shows a typical position once opened the door of the display unit.

Once obtained all data we elaborated them considering that data from M50 and F50 are statistically more relevant. To do this we gave a smaller weight to M95-75 and F25-5. In this way we obtained an average value of visibility for every shelf and position.

Display unit configuration, distance between human and display unit can be defined as parametric variables in a CAD and they can be easily changed to gather new results (e.g. blind angles) as shown in Figure 8.

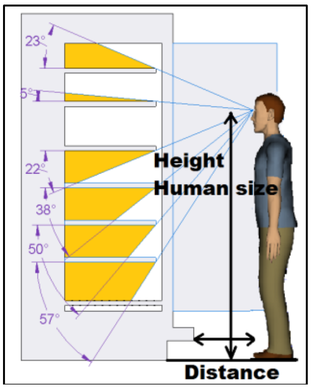


Figure 6 - Representation of CAD use in visibility evaluation

In case study 2 we considered also the influence of the structure on the visibility of the shelves. To do this we defined on a horizontal cross section of the display unit, the different positions and orientations that customer assumes once opened the door. In this configuration we looked for eventual blind angles on the attention cone of 40° (Figure 7).

Each of the elements described above can be modified in a parametric way so that changes can be measured and visualized quickly and easily both in a numeric and graphical way.

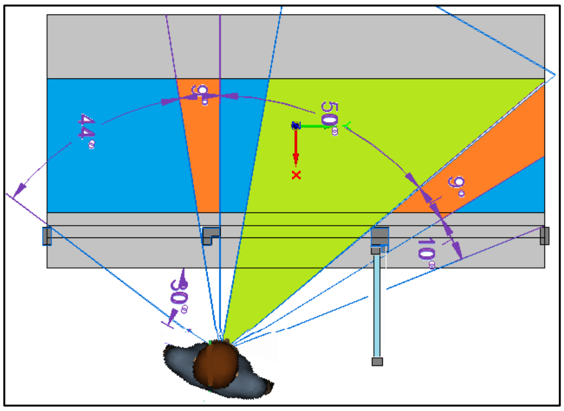


Figure 7 - Use of CAD system to evaluated proximity visibility.

4. Results

The case studies considered are two refrigerated display units: a high temperature without doors and a low temperature with doors. For each of them a similar analysis of reachability and visibility can be done but they differ for the presence of doors and frames and this imply different approach that drives to different results representation. In the followings some results are presented to show how effective a graphical representation can be.

4.1. Case study 1

Figure 8 shows which are the portion of the shelves that can be accessed by most of the customers (green), the portion hardly reachable by most of the people (yellow) and the portion nobody can reach (red). For each shelf an index is calculated by dividing the length of the shelf that can be reached by the entire length of the shelf.

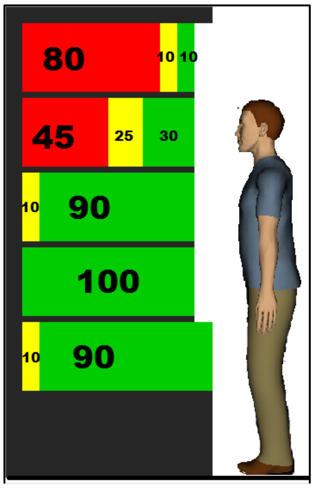


Figure 8 - Reachability case study 1

Concerning visibility Figure 9 shows an example of graphical result about visibility. Orange areas indicate the blind angles for a M50 subject at 1,5 m distance from the display unit. Having adopted a parametric approach for the product we can easily change shelves number and position and/or the height of the customer. This allows gathering all the required figures drawn in real time.

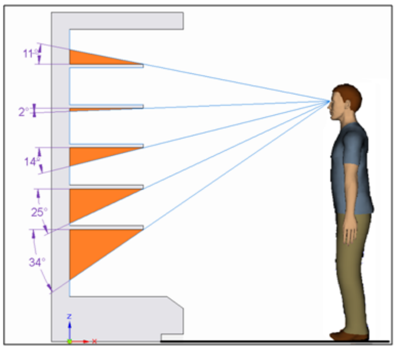


Figure 9 - Graphical representation of visibility of M50 from 1,5 m.

4.2. Case study 2

The second display unit mainly differs from the previous one for the presence of doors and frames that create a barrier for the customers. This motivates the simulation for reachability on a horizontal plane.

Figure 10 shows the result obtained for the 1th shelf and M95, green cells means no contact and optimal reachability, yellow cells means proximity to structure of display unit, red cells identify contact with structure and grey cells are not reachable.

							H-S							11
			H-S	H-S	H-S	H-S	H-S	H-D						10
		H-S	H-S	H-S					H-D	H-D	H-D	H-D	H-D	9
H-S	H-S									H-D	H-D	H-D	H-D	8
												H-D	H-D	7
A-F													H-D	6
A-F													H-D	5
A-F														4
A-F														3
A-F	A-F													2
A-F	A-F													1
14	13	12	11	10	9	8	7	6	5	4	3	2	1	

Figure 10 – 1th Shelf M95 homolog knee.

So, for instance, the cell in row 7 and column 2 tells the designer that the head of the customer is close to the door; the cell in row 2 and column 14 highlight a collision between the arm and the frame. Figure 101 shows a compact graphical representation of contacts for M50 and a low temperature display unit, this representation give evidence to those area that are easily reachable, to those that are reachable but there is a contact between human and structure and those that are not reachable.

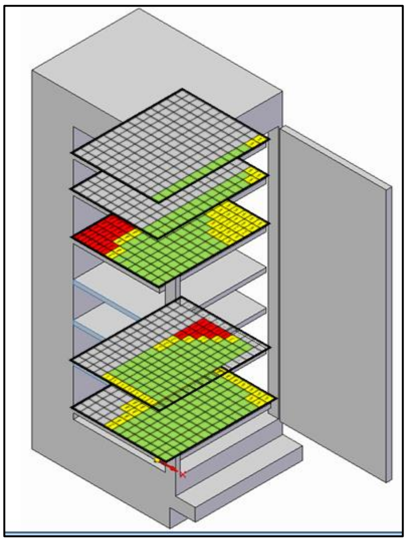


Figure 11 - Compact graphical rappresentation of reachability for M50 using Epta Elephant.

Due to the presence of door frame also horizontal visibility is a key parameter to be assessed. Figure 12 shows a graphical representation of visibility of a low temperature display unit with the door open. In this configuration the customer is rotated of 30° toward the open door as this is the most recurrent posture. Colors are used to discriminate different portion of the shelf. The visible portion of the shelf plane inside the attention view angle (40°) is green, blind angles are orange and other visible parts are blue.

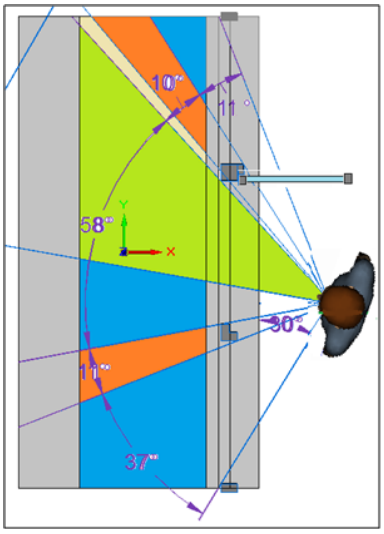


Figure 12 - Graphical representation of visibility for low temperature display unit.

Figure 13 shows the same kind of analysis where the door has been closed and distance of the customer increased up to 1 m.

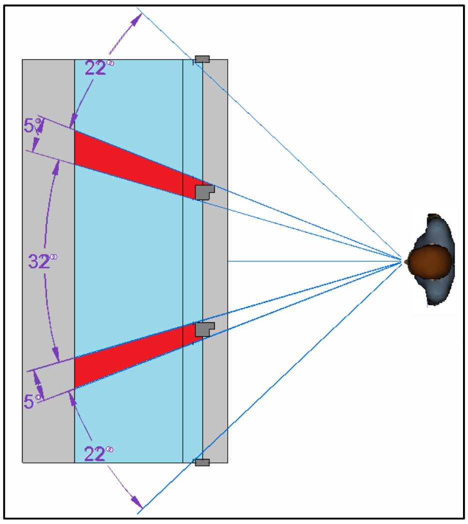


Figure 13 - Top view of visibility analysis from 1 m distance.

5. Discussion

DHM can be fruitfully adopted to assess product visibility and accessibility. The shown application highlights an effective way to provide results to technicians in charge of designing the product. In particular, this application suggested several triggers for the re-design of display unit architecture in order to guarantee a better buying experience.
This method permit to create a map of possible area where contact happened, identify which are the most probable body parts that could come in

contact and with which elements of the structure and, in an indirect way, to evaluate accessibility. Combining results from different human sizes and different postures highlight major problems. A sharp representation of results easily suggests solutions also about design of components as, for example, the doors layout.

There are still some issues due to the manual positioning of the human that requires some experience in using the tool to assure a correct result.

The results obtained with visibility analysis in case study 1 has been used at the company as guidelines for light positioning to augment visibility and reducing also energy consumption.

Visibility analysis on case study 2 has never been conducted on precedent works and represents a novelty since it gives the possibility to the designer to understand which parameters of frame layout can easily and quickly increase or decrease visibility.

6. Conclusion

The method proposed relies on the use of DHM and a parametric CAD system to extend the capability of analyzing visibility and accessibility of products that imply human interaction both in industrial and commercial environment, obtaining both a numerical and a graphical representation of results.

The method presented not only integrates the traditional use of DHM but permit at the same time to modify geometry of products and environment configuration in order to test many different product variants and obtain in real time important results. Another characteristic is that the results give a graphical indication that fit directly on the products considered putting a strong evidence on possible weakness.

In the particular case of display units this work had the aim to analyze step by step the buying experience and for each phase it individuates the proper test to highlight specific aspects.

The results of this work permit us to assert that Digital Human Modeling combined with CAD systems are an appropriate tools to evaluate ergonomics of products in the case studies considered of two existing display units and that could be used also to other products design in the early stages of design process itself for an earlier identification of issue.

The combined analysis of reachability and visibility together with a graphical representation of results provide the designers with a simple and powerful approach to ergonomic design.

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