Virtual Reality within a Human-centered Design Methodology

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Abstract:

The domain of virtual reality is advancing rapidly and holds great promise for design and visualization. Computer-aided design (CAD) and the increasingly widespread use of numerical models in an industrial context are encouraging the development of new tools dedicated to virtual reality. More particularly, a number of software packages appearing on the market in recent years show significant potential for product development processes. This article presents how these CAD products are being integrated into our ergonomic methodology relative to new product design. The objective is to help those involved in this kind of project to make design choices during the decision-making processes that respect the needs of the future users. The innovative character of our human-centered des ign methodology, which integrates virtual reality, lies in its contribution to improving the development process of new products. The innovative aspect of our human-centered design methodology, which integrates virtual reality, is its contribution to the improvement of the development process of new products.

Keywords: product design, human-centered design, ergonomics, simulation, virtual reality

1. Introduction

The changing economic context, marked by strong competition, is leading companies (enterprises) to innovate more and more in order to ensure their durability [12]. Competitiveness, which has become a major preoccupation and consequently "the engine of the company", is based not only on reducing costs and rationalising production, but also on increasing the quality and the use value of the products. Comfort and ease of use often make the difference between two similar products [3]. In this respect, the major interest of the industrial company is to satisfy the needs of its customers by a product offer that respects the well- known “quality-deadline-cost” triplet [22],[23]. The customer is consequently located at the center of its preoccupations. In this context, technological developments, in particular in the fields of Science and Information and Communication Technology lead companies quite naturally to reconsider their organizational systems and their development tools. This must be done insofar as it is advantageous to design closer to the request, to produce reactively and to manage increasing quantities of information.

The design and production phases, as well as the phases located downstream of the life cycle of the products (after-sales, recycling or destruction of the products), are increasingly being integrated companies.
In this constantly changing environment, companies are confronted with the appearance of many increasingly complex products which, in spite of their technical quality and reliability, are badly accepted or rejected by the users [22],[23]. Indeed, these are products that do not fully respond to the needs of the end user. For example, concerning the large-diffusion products, about half the users of video-recorders do not know how to record; the majority of owners of programmable room thermostats use them like simple switches; only two or three of the functions of a phone are usually used by more than one in thirty; or the adjustment of car seats has become so complex (seven settings, positions that can be memorised, heating device, etc.) that it can discourage the user.
Similarly, as regards production means, companies have for a number of years been receiving complaints from operators concerning working conditions, health, safety, etc. [22],[23]. The impact of this has been an increase in the number of work accidents, occupational diseases, and a higher

absenteeism rate, but also a deterioration of the social climate and of both the quality and the effectiveness of the Man-Machine system. Indeed, recent statistics show that the number of occupational injuries has risen significantly, in particular periarticular pathologies, better known as Work Related Musculoskeletal Disorders (WRMD) [1], [5]. These pathologies, multi-factorial in origin (work environment, organization and design of work stations, etc), are increasingly widespread [1].
It is within this context that our research is being undertaken, particularly in the area of ergonomic intervention in the design of products and systems through the development of knowledge, methods and transversal tools in two fields: Engineering Sciences and Human Sciences [22],[23].
Proceeding from the model of concurrent engineering [4], which has replaced the linear and sequential model of traditional design, we propose an ergonomics system capable of covering the entire design process the integrating the product - production means pair. The objective is to help designers to develop systems (products, machines, workplaces, etc.) by taking into account the needs and expectations of the users/operators. On the one hand our work aims to increase the performance and the reliability of the Human-Product, Human-Machine interaction modes, etc. On the other hand our work tries to guarantee the safety and the health of the users [23],[26].
In this context of concurrent engineering, the Information and Communication Technologies also play a dominating role in such an approach, insofar as the virtual model and rapid prototyping are tending to reduce the number of physical models. Through their capabilities, Virtual Reality techniques are thus able to immerse a user or an operator in an interactive virtual environment [10],[15],[24]. Moreover, they allow a rapid evaluation of the usability of various design alternatives. This is why they are particularly promising for the problems being considered. The major issue is therefore how to integrate them correctly at the design stage [2],[9],[20].

2. A Human-centered Ergonomic Methodology

Our ergonomic methodology aims to help companies to innovate by integrating human factors in the design of products and the associated means of production. In particular, the main purpose is to guide designers, from the initial phases of design process, in the evaluation of the consequences of their design choices, and in terms of the safety, comfort and effectiveness of Human-Machine dialogue [22],[23],[26]. With this in mind, we propose the development of an experimental platform to demonstrate and deploy the ergonomic design methodology developed within the research team on the Ergonomics and Design of Systems (ERCOS).
This platform, which requires to be both flexible and evolutionary, allows the integration of characteristics of the users (physiological and biometric data, age, social and cultural data, etc.) throughout the life cycle of the product to be designed. Consequently, according to the questions asked and on the basis of a diagnosis of existing work situations, various actions can be undertaken using the associated equipment: prevention, evaluation, correction or design of new products.
This objective of "total ergonomics" can only be achieved if ergonomics is present at every stage of the design; the methodology suggested and the associated platform therefore require the adoption of a global approach to the Human-Product-Environment system (H-P-E system). This methodology was applied partly within the framework of various design projects of new product development programmes (the French High Speed Train – TGV, car, subway, etc.) and new workstation design [16],[23]. Until now, three complementary phases of study and design have been defined and developed (see figure 3):

- the feasibility study: observation and analysis of existing use and work situations. The H-P-E system is studied in the real situation,
- the preliminary study: search for solutions, based on the virtual simulations of desirable future gestural activities, using numerical mannequins (MANERCOS) [17]. The H-P-E system considered in this case is entirely virtual,
- the industrialization: evaluation and validation of the selected concepts, through "realistic" simulation of use and work activities. The H-P-E system analyzed is thus "realistic", i.e. a real man uses a physical prototype of the product within a virtual environment. For example, this is the case of Human-Machine interfaces, in a car or train driving simulator [16],[17].

The results obtained at the end of these various phases of study are encouraging. However, they highlight the need to introduce new approaches and new tools into the suggested methodology. In particular, it is a matter of integrating virtual reality into the human-centered design process. This is the subject which will be presented in the following paragraphs.

3. Towards Virtual Reality within our Human-centered Design Methodology

As illustrated by figure 3, the innovative character of such an approach is founded on its capacity to design new products by the means of real activity analysis tools during the feasibility phase, the use of the tools for numerical modeling and simulation of gesture and postural activity during the preliminary study, and in combination with "realistic" activity simulation tools during the industrialization phase [22].

A multi-field approach is thus possible through this ergonomic design approach by the association of engineering and human sciences [22],[23].

With the ultimate aim of better design in mind, we are considering enriching our methodology by proposing the integration of new tools that could help the development of this methodology. Indeed, we noted the necessity of an intervention between the virtual system HV-PV-EV (stage 2, figure 3) and the "realistic" system HR-PR-EV (stage 4, figure 3).

There are obvious reasons including the cost and development time of a physical simulation platform and the fast transition of the product to be designed from the virtual model to the real model.

In the domain of transport (i.e. railway and road), we encountered difficulties in installing the flexible simulation platforms, which are able to integrate and test various types of systems intended to assist driving.

Consequently, it seems to us more complex and difficult to develop such a physical platform to model and to evaluate production means prototypes. The wide variety that exists makes experimenting during the industrialization phase very difficult and expensive. Moreover, the tests carried out with "real" users to assess the real models of the products have highlighted the necessity of late modifications. It then appears essential to add to our methodological approach an intermediate phase, prior to the "realistic" simulation stage. This new stage will permit testing with "real" users, but this time on virtual models of the product and in a virtual environment. This will be possible through the continuous development of numerous virtual reality tools [6,11,14,21]. These will contribute more and more to substituting physical models of the products by virtual models, which are easy to modify [2],[8].

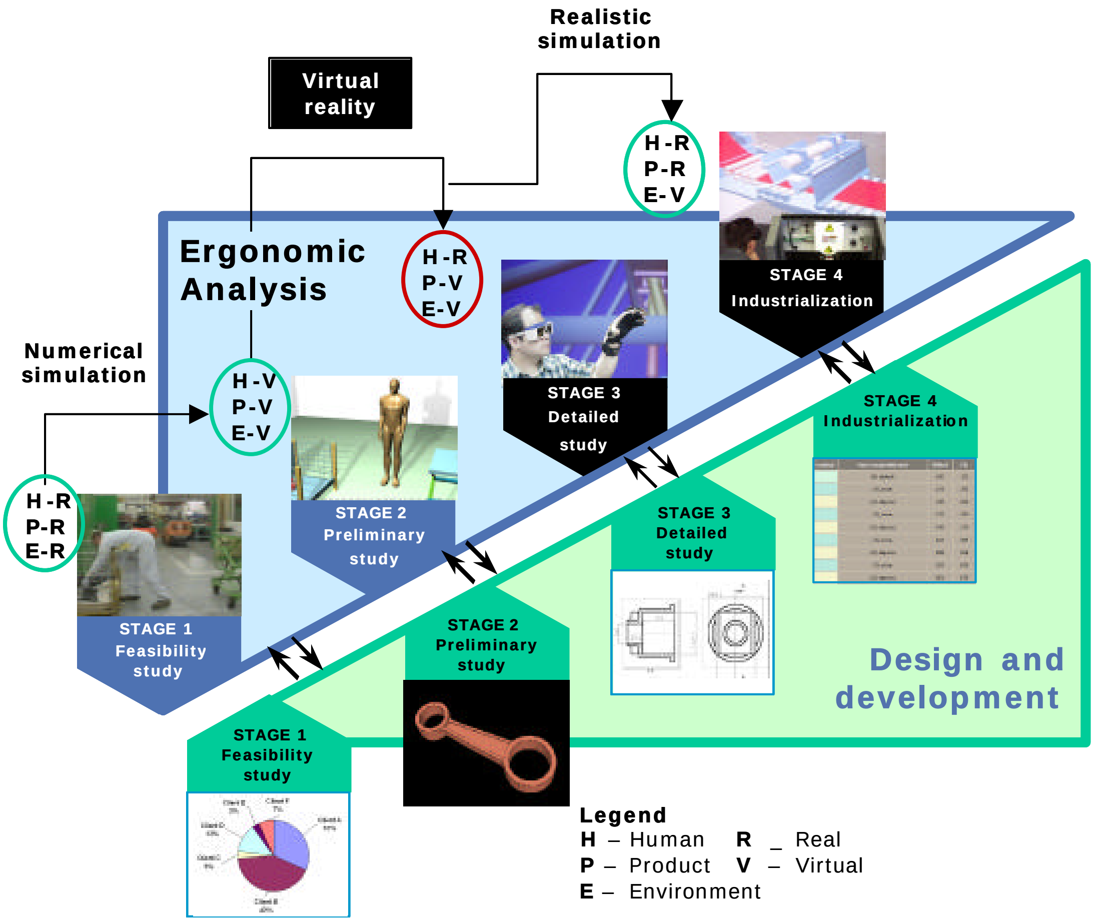

Figure 3: Stages of our ergonomic methodology – Application to the design of workplaces

The use of virtual reality tools will thus allow a real human to be immersed in the virtual environment where he can interact with the virtual products [8],[19]. This approach contributes to full consideration to human characteristics very early in the product design [24]. The figure 3 illustrates the evolution of the suggested methodology, but applied to the specific field of production means design. It emphasizes the "ergonomic analysis-product design" link and the associated equipment necessary for measuring and evaluating this relationship.
These must be used during the development process of the products, the production means or the production systems in order to allow a human-centered design [6],[11],[14]. Moreover, virtual reality tools will represent a real support to multidisciplinary cooperation between those involved in the design process (engineers, ergonomists, computer scientists, designers,). One example is the use of a Computer-Supported Cooperative Work system, such as the ACSP [17], which encourages communication, the exchange of ideas and the comparison of viewpoints [18].

4. The experimental platform

As indicated in the preceding section, virtual reality is at the center of our ergonomics design methodology. In this respect, our laboratory considers the acquisition of a virtual reality platform, illustrated by figure 4, in order to construct the missing link and to apply the suggested methodology. The objective of this platform is to immerse a real user in a completely virtual environment. Thus, it will be possible to check and validate the design of a product on a virtual model. Obviously, the immersion necessary for such an approach requires an adequate hardware infrastructure. For this, it is necessary to take into account all the senses of the human operator who will interact with the virtual world [10].
Based on a workbench system and two data gloves, the platform will have to give the illusion of immersion. For this, we chose a double-side screen accompanied by a stereoscopic display system based on active glasses (figure 4). The choice of a double-side screen seems to us the minimum requirement to simulate an immersive environment correctly within the framework of a ergonomic design approach. It is the result of a compromise between financial resources, visual immersion quality, obstruction and the embarrassment caused to the operator by the display system. However, we will be able to consider the addition of a third screen to form a system much closer to more immersive ones like VR-cube™ or MoVE™ [19].

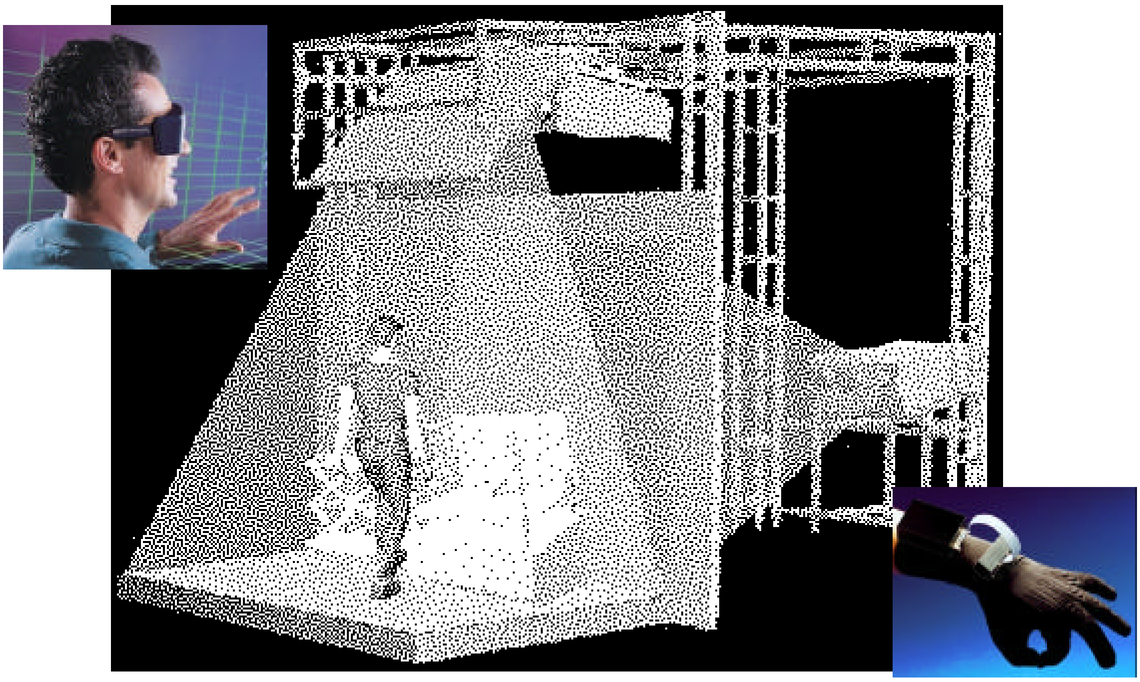

Figure 4: Our project of virtual reality platform based on a workbench system connected to data gloves

The visual environment generated by the 3D calculator will result directly from the models developed by CAD tools already in use (especially from MANERCOS). Moreover, we will propose a set of programming libraries or API allowing these various tools to interact directly with the virtual reality platform. Thus, the environments in which the MANERCOS numerical mannequin evolves could be directly transposed to the platform. This will allow an easier comparative study between the behaviors of the digital model and the human operator, which are immersed in the same virtual environment. This will also allow the operator to visualize the work gesture activities simulated by the numerical mannequin.
The second sense that will be taken into account in the the immersion is the tactile sense. Until now, our activities have been limited in scope to capturing information concerning the spatial location of the body of the operator. However, for more detailed ergonomic studies, we are considering the addition of sensor systems allowing recovery of the angles between the various body segments of the operator (system already developed by ERCOS). This objective forms part of the longer-term aim of integrating at the design stage the efforts exerted by the operator to handle and use the product. However, capture of the efforts requires haptic systems which are the subject of interesting research prospects [7].
Of the three other remaining human senses, we will only take into account hearing. The simulation system of a sound environment must be included to give the human operator a complete illusion of immersion.
At the present time, due to the embryonic state of our work on this future virtual reality platform, we do not have any scientifically convincing results available.
In addition, we are also working in partnership with the SMA-SeT (Multi-Agent Systems) research team to develop models linked to the numerical mannequin with a view to integrating them into the virtual reality environment under development. These multi-agent models [13] will allow easier and more effective simulation of instinctive and anthropometric behavior, as well as the interactions between them.

5. Conclusion and Perspectives

The design of products is a complex process that takes into account the human ergonomic problems associated with their use. To answer these questions, we propose an ergonomic design method centered on the human. Our previous work revealed a set of stages in the product life cycle. These stages allow the changeover from a completely real H-P-E point of view to a completely virtual H-P-E model, resulting finally in a model for a simulator where only the environment remains virtual. However, we consider that the changeover from a completely virtual representation to this final stage poses practical technical and industrial problems. In addition, the modifications highlighted during the use of the simulator are more difficult to take into account at the preceding stages.
All these issues led us to introducing an intermediate stage based on the use of a virtual reality platform. This new stage allows the comparison of a real operator with a virtual model of the product undergoing design. Ergonomic anomalies are therefore highlighted earlier, and are thus easier to correct in the product design.
In this respect, we are considering adapting the models developed for the MANERCOS numerical mannequin to allow their integration into the virtual reality environment presented. In addition, multi-agent models are being developed which take better account of the anthropometrical constraints of the operators as well as the structural constraints of the environment and the designed product. Lastly, we envisage the acquisition of the virtual reality platform described in this article.
Finally, regarding the proposed methodology it is important to specify that the “realistic conditions” of the ergonomic tests carried out in the industrialization stage can in no way be a substitute for real conditions, where new difficulties may arise and new functional needs of users may come to light. Thus the production means prototype studied is tested in real situations for the final validation and then it can follow the others production stages.

6. References

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