UCD Method using VR and related techniques for designing complex system

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Abstract: User Centered Design (UCD) considers the users and their needs throughout the process of design of a software application. In the case of the design of a mixed product (including software, and mechanical and electronic equipments), difficulty resides in the production of an object that can be evaluated at each iteration of the design cycle. The use of Virtual Reality and related techniques as Augmented Virtuality and Augmented Reality bring an affordable solution to allow iterative evaluation as defined in UCD. We propose an adaptation of UCD which simplifies the transition from the concept to the end product. We apply this approach to innovating assistive robotics.

Key words: Human/User Centered Design, Complex System, Assistive Robotics, Virtual Reality

1. Introduction

1.1. Context

The design of a complex and innovative technical assistant to assist a physically disabled person poses specific problems which it is necessary to take into account in the design methodology.
First, the number of disabled people is small and has very heterogeneous characteristics. The problem is to adapt methodology to these end user specificity and their very variable needs to design an adaptable and evolutionary product which respects the constraining socio-economic criteria and evaluations during all the process. The intermediate prototype must have sufficient adaptability to answer the variability of each user. The low number of user and the characteristics of each person bring the problem of protocols and validity of the results of evaluations.

Secondly, the technical assistant specificities have to be taken into account. Because of its innovative character the user encounters difficulties to clearly define his requirements in term of needs. In order to evaluate the contribution of the assistant, questions are: how to identify the majority of these uses (more than those envisaged) without spending time in discovering phases? How to put in situation the user whereas the object does not exist?

Thirdly, the object is complex. In handicap applicative domain, we define the complexity by an object made up of software and hardware components of approximately equal weight. The whole system needs competences in several disciplines as mechanics, electronics, data-processing, informatics architecture, electrical engineering…The socio-economic factors of the domain force to reduce complexity by establishing an adequate compromise between complexity and use. This can be done by implying more the user in man machine co-operation. Also, it is possible to reuse, as much as possible, marketed components. This last point also poses the crucial problem of the inter working of heterogeneous components.

Finally, the last question and not the least, relates to the evaluation during the design process. To avoid an immediate rejection by the users, it is necessary to ensure the reliability of an intermediate prototype and the progressive catch in hand of the object. Indeed, complexity makes the system hard to use, all the more if the user is handicapped. The proof of the contributions and the limits of use of an innovative and complex object by a population presenting deficiencies cannot be concluded without a phase of training. Indeed, the easy use of the system is not immediate. This problem increases in the case of evaluation during the iterative design cycle of an intermediate prototype.

After a short presentation of the two design methods the most used in industry, we introduce our proposal for an adaptation of the User Centered Design (UCD) which offers a response to domain specificities of innovative and complex technical aids. Then the techniques related to virtual reality (VR) are described, making it possible to implement this approach. We then present implementation of the method and its limits. Finally we illustrate on concrete examples how the approach of design and, more particularly, the techniques of the VR offer an answer adapted to the needs. The examples relate to the concrete case of the robotized assistant developed within the framework of project ARPH (Assistance Robotized for Handicapped People).

1.2. Traditional design

Figure 1 presents the two production process currently most used. It shows the “V cycle” and the “spiral cycle” models. In the “V cycle” model, the user first expresses a need. The industrialist answers it by presenting a schedule of conditions to him which then acts as contract between the two parts. The industrialist makes then the analysis, the design, the realization and the tests. He only meets the customer for the end delivery of the product. In the spiral model [BO1], even if the stages of the production process are identical, the customer is regularly asked for contribution to validate the intermediate choices makes by the industrialist. (This kind of method is particularly well adapted to human machine interface or software development).

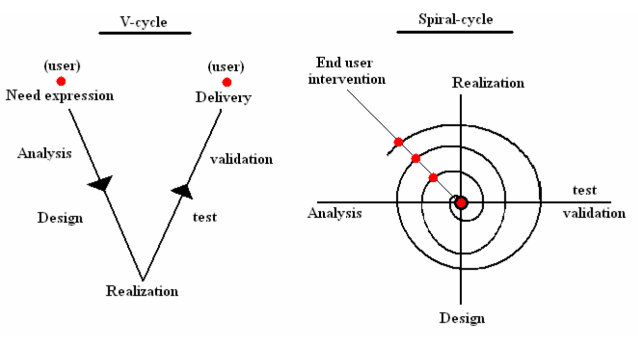

Figure 1: “V cycle” model and “spiral cycle” model

The contribution of the “spiral cycle” model compared to the “V cycle” model of development is thus the possible implication of the customer to redefine or check at each iteration if the need expressed at the beginning is well understood and transcribed and thus, to allow a better satisfaction of the customer at end delivery.

2. User Centered Design for Complex System (UCDCS)

UCD (User Centered Design) principle is that the user is best placed to evaluate and to influence the development of a product. The ISO13407 [IS1] standard defines the conditions of the implementation of a process centered on the human. Five principles are necessary to satisfy this standard:

1. The taking into account of the users at the beginning of the project, the tasks they want to do, and their environment

2. The active participation of these users and a clear comprehension of their needs and requirements related to their tasks.

3. A suitable distribution of the functions between the users and technology

4. The iteration of the design solutions: we can think the cycle like a spiral followed until the system satisfies the requirements defined at the beginning.

5. The intervention of a multidisciplinary team of design, in particular for the evaluation which is not limited to simple considerations on the utilisability but have to implement rigorous methods of collection and data analysis.

However the standard ISO 13407 was designed to define UCD for dominant software applications. The confrontation of the principles of this standard with specificities of innovative technical assistance domain stated in introduction reveals difficulties of implementation.

The needs are badly defined at the beginning, but, we could imagine that they are re-evaluated, to a certain extent, at each design iteration cycle. However it is financially inconceivable to make an important modification of the material component of the complex object, such as defined in the introduction, at each step.
The principal blocking point relates to multiples evaluations by the end-user. There is on a side a complex object under development which it is necessary to make reliable for two reasons: the rejection by the user of the system and especially the safety. On the other side, it would be necessary to have several prototypes to obtain results considered to be valid statistically within acceptable temporal limits. Moreover, there is the handicapped user, often not very available for reasons of health and very variable characteristics. Each person is to be considered as a particular case. This large variability brings up interrogations about the validity of the evaluation results.
The principle number 3 enounced previously is well appropriate for the philosophy of the assistance to the person, as it is defined by the majority of the actors of the handicap domain. Indeed, it requires an implication of the person by establishing close man-machine cooperation (MMC) with the provided robot. In addition, this MMC makes possible to reduce the complexity of the machine, because of the user presence, by the design team. In this

case, the user and the machine are considered as one system able to satisfy the realization of functions distributed statically or dynamically between them.
Another important factor for the reduction of the complexity of the system and thus of the costs is the re-use of marketed components. However, the re-use has also a cost to manage heterogeneity constraint of the solution.

We now expose principles which led to the development of a new method. Then we described the method itself. After the presentation of the techniques used, we discuss about contributions of the method. The last paragraph exposes derived advantages.

2.1. Principles

To answer the previous interrogations we propose to adapt the UCD. In the “spiral cycle” model, the user only contributes to validate the product at each iteration cycle. The “spiral cycle” model also implies to duplicate the material prototypes for evaluation, which is not possible taking into account the economic and social factors of the applicative domain. Moreover, specificities of the handicapped users bring up the question of the statistical validity of the data collected during these evaluations.

The most important is to involve the user throughout the process of design not only to validate the functions but also to participate to design by being implicated in concepts definitions. The concept is an ability of the system and the function is the implementation of this ability. For example, imagine we have a mobile platform. A concept could be the possibility to add the ability to seize objects. The function related to this concept is, for example, the use of an embedded manipulator arm to satisfy the realization of the concept.

As we place ourselves from the innovating object design point of view, we distinguish the evaluation of the concept and the evaluation of the function. To validate the concept, it is necessary to place the user in situation such as it can apprehend the interests of it. In the case of the function, it is necessary to approach reality, so, that the user can consider limits brought by the implementation of the concept. The interest of this distinction is, initially, to check if the user has the use of this concept and then to check if the realized function answers correctly its waits.
The strong economic constraint imposes the construction of at most one real prototype at each iteration cycle for whole validation of the concept and related functions. This implies to be able to present to operator an intermediate product which mixes concept and material reality.

In short, the two encountered problems are the cost of prototype development and the difficulty to validate concept with a material system. Virtual reality techniques [FT1] permit to solve these problems. Firstly, the cost of development of a virtual prototype is strongly reduced compared to the development of a real prototype. Secondly, VR permits to evaluate concepts. In the previous example, we could models a mobile platform in a virtual environment. The user can then move the platform toward the object to seize. Then, the user has just to designate the object which is automatically seized. The evaluation of the related function is more complicated because it needs manipulator arm modeling and the implementation of the control of the global system (mobile platform and embedded manipulator arm) by the operator.

Next paragraph explain the implementation of the previous proposed principles using UCDCS (User Centered Design for Complex System) method.

2.2. UCDCS: a two plans design method

There, we extent the spiral cycle design model to construct UCDCS scheme showed on figure 2.
We find the same phases as in the traditional “Spiral” model. Whereas this model proposes a single plan method, UCDCS is a two plans one. Design and production steps can be realized in a virtual plan or in a real one. User expression and validation steps are common to the two plans. Analysis and evaluation steps represent the turning axis. Analysis step permits the choice between virtual plan and real one. The two plans joint together at the evaluation step. The horizontal plan is the traditional one use in “Spiral Cycle” model; it represents the production of a real product. The vertical plan is the virtual design one. At each iteration cycle, after a need notification and the phase of analysis, we offer the choice between a rapid prototyping cycle (virtual) and a real production of a prototype. Between these two plans, there is the mixed reality space which permits us to present a mixed product combining virtuality and reality.

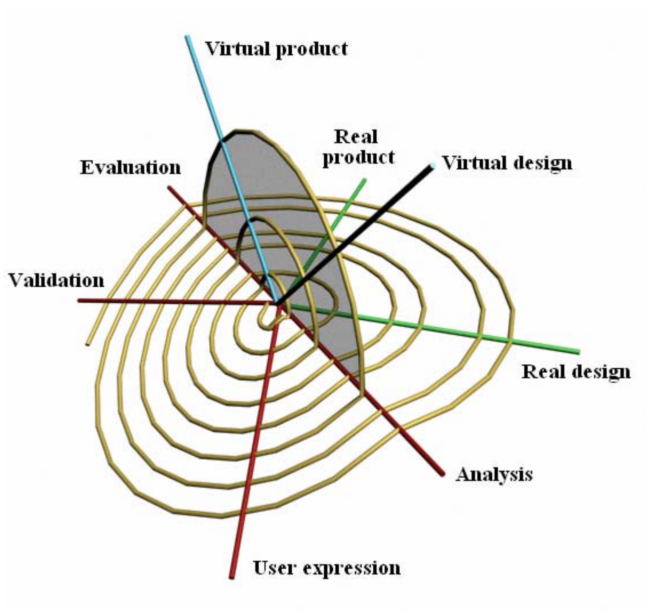

Figure 2: UCDCS Scheme

For example, let us suppose that the process of design begins by the concept of an innovating and remotely controllable assistant, to handle distant objects, for handicapped person. When process is initiated, the object is a virtual one. It can be extremely simple and, for example, represented by a virtual hand able to move in the environment. The first evaluation of this simulated innovating object consists in asking the user if it has the use of it. In the affirmative, the following stage consists in finding the various functions which make possible to produce the object, by starting for example with the mobility function. The mobile base is designed and we evaluate the capacity of the handicapped person to use it. We reiterates until validation. There are two possibilities to evaluate mobility: simulation and/or realization. Simulation will validate a simplified mobile object: structure and man machine interface. It is essential because it makes possible to put the user in situation and not only the designers [ST1]. Thus, he better apprehends the difficulties and the limits of the various solutions. After some iteration, when simulation does not make evolving solution any more, there is construction of a mobile platform which integrates specifics constraints not taken into account previously in the simulation (reality, technologies, re-use, cost, maintainability…). This additional stage has the advantage of confronting the user with an object in interaction with its environment and submitted to physics laws (acceleration, slip…). Using the real mobile platform prototype, it is possible to add a new concept (as the seizure one exposed before) and then entering a cycle in the mixed reality space.

In short, we build the product starting from a completely virtual object innovating by gradually replacing the virtual functions or components by their real clones. The process finishes when the product is entirely real and validated.

By entering as much as possible the virtual cycle, we strongly reduce the need for a new real prototype at each iteration cycle. VR techniques, as described in following section, also offer advantages that permit to multiply evaluation, by using low cost simulation which can be distributed to a large number of people, increasing at the same time statistical validity of the results.

This method can be use from the beginning of a project, to make an existent system evolving.

2.3. Virtual reality related techniques

Except the virtual reality (VR), we will use related techniques to this domain [FM1], such as augmented reality (AR), augmented virtuality (AV) and Mixed Reality (MR):

AR consists in pasting synthesis components in a real world image [CM1]. The added components [FM1] can be of diverse kinds: text, image, documentation, virtual object… During the evaluation, as parts of the object are real (especially video), it is easier to put the user in a more realistic situation. It also provides help for a best comprehension of environment [HT1] or to facilitate for example maintenance of a product like in AMRA project [DR1].

AV consists in adding to virtual environment reels components as for example textures [SA1]. This technique is more delicate to implement because it engages more resources. However, it has many advantages like the possibility of including in a simplified virtual world the dynamic properties of a real object without having to model it with precision. Thus, we have the dynamics of some material components of the system and, at the same time, the ability of moving in very various virtual environments which do not exist in reality.

We can link real and virtual with a straight line. Mixed Reality (MR) can be defines as a cursor moving all along this line. It's a mix between Augmented Reality (AR) and Augmented Virtuality (AV) [MK1]. Several examples are given in [MB1].

The vision is the richest human sense for information wee need. That justifies we limit ourselves to the visual approach in using VR techniques.

2.4. Discussion

In general, it is not simple to validate the use which will be made of a product by using only virtual reality. The cost of a hyperrealist simulator by modeling the environments, dynamics and human is infinite. Modeling is a complex task and VR systems require expensive equipment to obtain a near reality immersion, therefore difficult to move and duplicate. It is often necessary to make evaluations directly at one or more handicapped people home. We drew aside the idea to validate all the system in simulation before the real production of the system. We rather wish to position us on rapid prototyping. Thanks to that, we target a better design (since we can validate the concepts into virtual) and also a better real validation by successive real system prototyping. Indeed, the a priori validation of concepts and functions strongly decreases the number of cycle of a traditional spiral process, inducing time and physical resources important gain.

In our approach, the environment and virtual component are generated in a simulator by using only the vision. The objective is to sufficiently put the user in situation to validate a concept. The simulator doesn't need to be hyperrealist but must respect the compromises "implication level/cost" and cost/contribution in the design. The immersion of the person in the simulator does not need to be total. We seek a sufficient presence level [FM1] to validate such or such idea. The feeling of presence of a person in a virtual world does not only depend on the degree of realism. The human person is sufficiently intuitive and adaptive to understand a simulated environment far away from the real world. (The video games are not always of a great visual quality, which does not prevent the players from being invested and to be strongly present, thanks to the dynamic behaviors, symbolic and well designed play games). The correspondences between real and virtual worlds are the subject of many works [FM1]. The results show that many factors have to be taken into account. Here, we formulate the assumption that it is possible to find a compromise between user implication quality in the virtual world, the effort of production of the simulator and the contributions for the design of the innovating product.

On figure 2, we see that if we approach at least one time each plan, we have a simulated and a real system. Thus, we can plan mixed evaluation phases which will combine virtuality and reality. So, it provides us additional tools for a better evaluation of the starting concept.

The Mixed Reality (MR) space (figure 3) is delimited by the virtual plan and real one. It can be declined in an infinity of MR plans going from the Augmented Virtuality (several virtual modules and few real ones) to Augmented Reality (several real modules and few virtual ones).

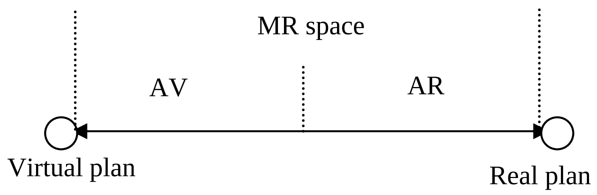

Figure 3: MR,AV an AR spaces

VR applied to UCD gives the possibility to validate the end product but also permits to evaluate concepts before they are applied. It's no more necessary to build a real prototype at each iteration cycle.

It should be noted that, at the end, we have at the same time a real operational system and its simulation. Then, we have, without another additional development, a reliable and sufficiently realistic training system [TH1] for the user.
One important element to take into account when speaking about design costs is thus the parallel realization of a training tool during the design process.

2.5. Advantages and consequences

For a handicapped user, the training for a complex system is one of the principal difficulties. We can plan for the training to follow an iterative approach using the simulator built at the time of the phase of design. We can also plan to initially confront the user with the concepts, then with a simple object that we will complicate until the end simulated product. Another particularly interesting advantage is to make it possible to the future user to take more risks than with the real system (analogy with a player which loses the real notion of dead in a video game where the number of life is infinite). Experiments in progress let us think that the simulator makes it possible to consider more easily new strategies and thus appropriate the system more quickly. We will check this point in future experiments by analyzing the competences transfer on real system after a training on simulator. We'll see if the strategies used are the same ones for a person having learned only on the real system.

This tool which facilitates the training is of double interest. On one side, the user can familiarize himself with the functions of the system before the use of the real robot when the product is marketed. In addition, this phase of training is necessary in the process of design itself. Real or virtual, the system is complex and its use is not immediate.

Figure 4 shows the various constraints related to the complex systems. Cost constraints intervene directly on material components because targeted users may acquire the marketed product at a low price. Psychological constraints must be taken into account principally for all human machine collaboration algorithms and for material design. The evaluations constraints (EC) intervene on the whole project and are detailed in the next paragraph.

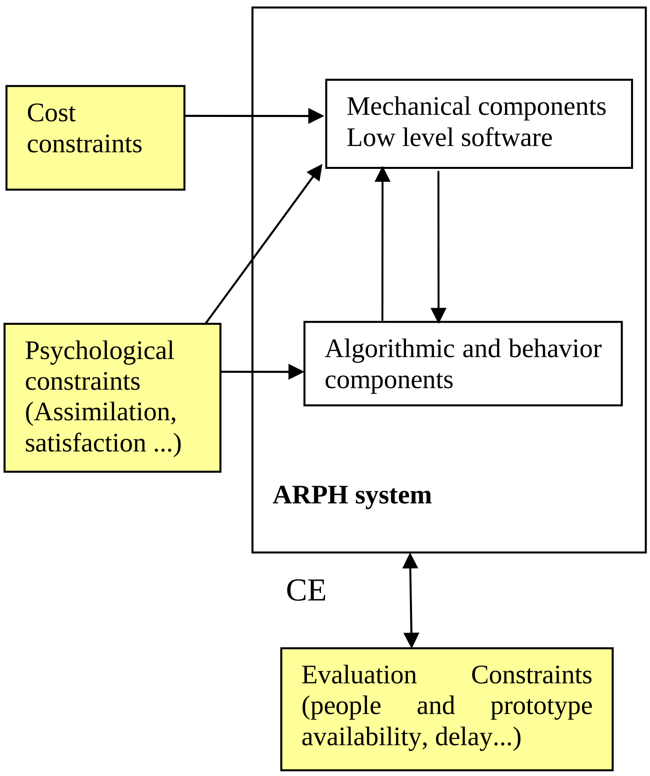

Figure 4: Complex systems constraints

Our design makes it possible to limit in a direct way those related to the cost. By decreasing the cycle times, we think that the interest of the user for the product will be preserved, implying a greater satisfaction. The EC mustn't be under estimating in this type of project where the human is implied. They represent the constraints related on the availability, the deadlines and the costs induced for the phases of tests and evaluation implying the end-users. By decreasing the number of cycle, we limit these phases. By proposing a simulator which makes it possible to approach them at home using a simple computer, we can parallel these phases and thus largely limit these constraints while possibly increasing the number of tests for reliable statistical studies. It is an additional argument which militates in favor of a limitation of the complexity of the simulator.

3. UCDSC implementation

To make UCDCS works, several indicators must be defined to determine when it is the right time to commute from one plan to another one or to stop the process in the iterations' cycle at the end of analysis step. Once these indicators are clearly identified, the implementation of the method is deeply exposed. Finally, some limits are presented.

3.1. Indicators

The first indicator to develop corresponds to the commutation from the virtual plan to the real one. In other words, how is it possible to know when the design iterations' cycle in the virtual plan is sufficiently advanced to realize a prototype and to commute to the real plan? To do that, it is important to quantify the contribution of a new iteration in the design process. Three factors must be used. The first one concerns the transformation rate of the virtual product. The higher it is, the more it is important to make it in the virtual plan. The second factor is the success rate of the subjects to the evaluation tests. The lower it is, the more it is useful to transform the virtual product.). The third one concerns the schedule of conditions. It is not necessary to reiterate on the virtual plan if the user and product specifications are satisfied.

The second indicator deals with the commutation from the real plan to the virtual plan. When the design process takes place in the real plan, an evaluation of the system is performed. The question is then to know if the prototype answers to the schedule of conditions. If yes, the design process is ended and the production can begin. If no, the question is to choose between little improvements that can lead to a answer the schedule of conditions or important changes that implies to go back to the virtual plan.

These two global indicators have to be shared to take into account the Mixed Reality (MR) space. We have to attribute to each part of the system one indicator. Indicators have 2 states: Virtual or Real, depending on analysis step of the current cycle. When all off them are in state Virtual, we design on a pure virtual plan. When they are all in the state Real, we design on a MR plan. If some are in the state Virtual and other in the state Real, so, we design in MR space. The ratio number of virtual states/number of parts of the system indicates the progression of the design process.

3.2. UCDCS implementation

We now describe the implementation of our method. We begin by a simple application of the UCDCS, then we propose more advanced diagrams.

From the starting concept, the simple implementation of UCDCS (figure 5a) consists in iterating in the pure virtual design plan.

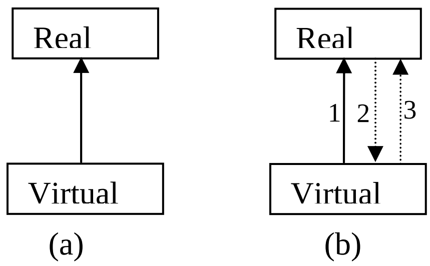

Figure 5: (a) simple implementation, (b)simple with loop

The concept and the associated functions are validated in the virtual plan with the help of the previous explained indicators. We then enter a design cycle on the real plan until evaluation and validation steps. At the end of this cycle, if the product satisfies the schedule of conditions, it then leads to a marketable real product. If it appears some minor defaults, it is possible to loop on a real plan again. If analyzed defaults are more important, it is then possible to go back once more on the virtual plan (figure 5b) and reconsidering the real plan after correction of the problems. Let us note that in this second case of figure, we think that the users, having assessed the real system, have a more realistic vision of the product. So, when they assess the virtual system again, next virtual design cycle grows rich by new behaviors which didn't appeared at the time of the virtual design at the beginning of the project.

The standard UCDCS makes it possible to introduce between the virtual plan and the real one a Mixed Reality (MR) space. As in the preceding case, the design begins on a virtual plan (figure 6a).

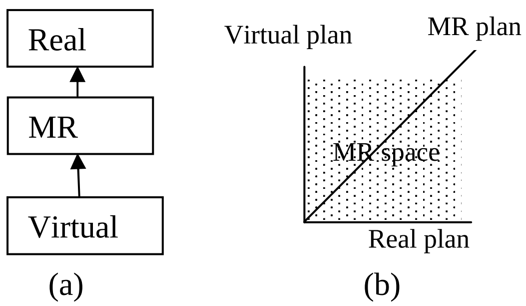

Figure 6: (a) Standard UCDCS, (b) MR space exploring

Progressively, in theses cycles, evaluations show that some functions implementing parts of the concept do not evolve any more. It is then possible to realize prototypes of these parts. We then enter MR design cycle associating this function in the form of a real prototype and immature concepts/functions in their virtual form. While iterating in a mixed space design, we fulfills little by little all the functions in reality until obtaining a completely real end product.

Let us note that the MR plan (figure 6b) moves from virtual plan towards real one. However, we should not exclude back way if a function implemented into real plan does not satisfy goals, requiring then to be reevaluated into virtual plan. In the same way, if evaluation results show that the MR product do not correspond to user waits, it is possible to return in a pure virtual design cycle.

UCDCS can also be applied in a different way (figure 7). As in the simple case studied before, the project begins on a virtual plan to lead to a prototype on the real one. The evaluations can then show that one part of the system satisfies specifications that another one does not. Rather than to reconsider a pure virtual cycle design, it is possible to reiterate on a MR plan. We then loop between RM plan and real one until having a completely real and satisfying system. This mode seems particularly interesting when objective is, for example, to find the best placement of the various mechanical parts of the system.

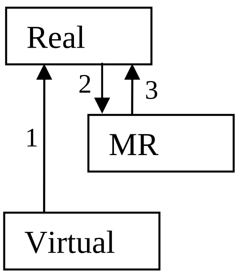

Figure 7: Extended implementation

Until now, we described UCDCS starting from a single concept. However, it is possible that a function satisfying part of the concept already exist in reality at the beginning of a project. In this case, design can begin on a completely virtual plan (after modeling of the existing part), knowing that this function is immutable and thus, is not subjected to modifications in the virtual world. We can also imagine to start directly on a MR plan including the existing real part and the virtual concepts/function missing.

It is also possible that a real complete system already exists. If this product, developed by using the traditional methods do not satisfy the users, it is then possible to make it evolve by applying the UCDCS. We can, for example, start on a MR plan if the objective is to modify a single part of the system which does not fulfill the requirements. If we don't know a priori which part is responsible of the bad satisfaction, it is possible to start on a pure virtual plan.

Figure 8 shows the various cases of uses explained previously by showing all links between the virtual, real and mixed plan.

The various implementations of UCDCS suggested have an interesting consequence: the greater facility to take into account possible modifications of the schedule of conditions. The impact of specifications modifications in a virtual design cycle is much lower than the impact these modifications could have on a completely real prototype. It is obvious that at the end of the real design cycle, modifications would lead to important cost, being given a real and finalized prototype. Let us note that the use of the Mixed Reality offers a priori an interesting alternative, in the case of modifications which will only be applied to a single part of the system.

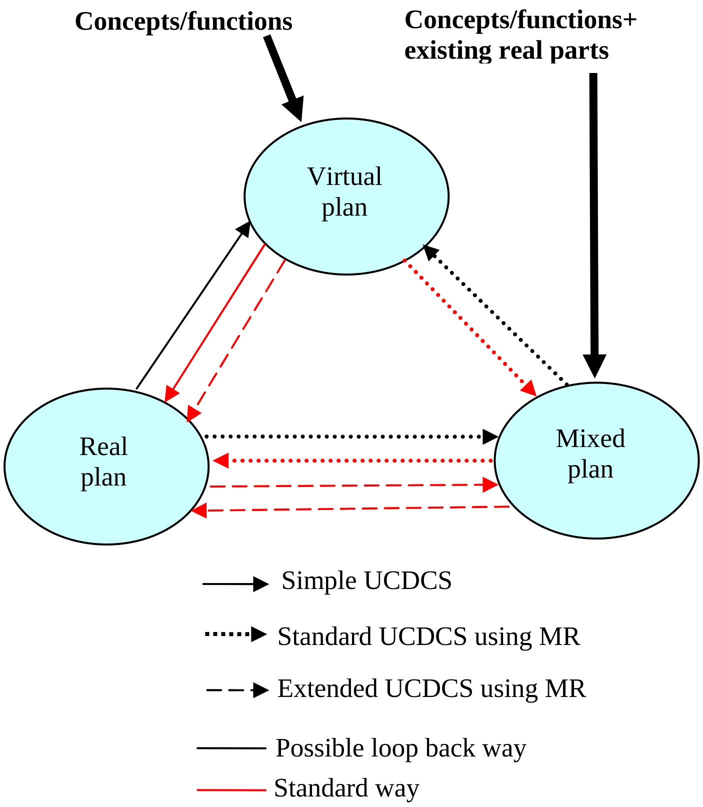

Figure 8: UCDCS global implementation scheme

3.3. Limits

We now describe the operational limits to be taken into account before implementing UCDCS as previously suggested.

First, the perception of the environment by the user with a low cost simulator and runnable on any actual marketed PC makes its immersion more difficult. The difficulties come from two points. The first one concerns visual realism when user does not act in the virtual world. To obtain hyper realistic visual aspects of objects, we need to use specifics graphical hardware interfaces and eventually a lot of computing power if some 3D calculations are supported by the main processor. The second one deals with the modeling of the fine interactions between the objects when user interacts with the virtual environment. The cost of a simulator including deformations and very realistic dynamics behaviors is, in the same way as visual aspect, also unacceptable to preserve a good contribution/cost ratio. For example, we could imagine the design of a product for semi-automatic hairstyle requiring the modeling of the hair and the interactions between it and the hairstyle system. It appears unthinkable to evaluate the complete product on a pure virtual design plan because of the huge complexity needed. The degree of visual and dynamic realism is dependent on the kind of product and especially to what we really need to evaluate. In the hairstyle study, it is for example possible to evaluate the look and the manipulability of the apparatus by iterating on a Mixed Reality plan. Within the framework of our study, we will particularly take care of preserving a sufficient degree of presence to satisfy the validity of the evaluations.

Secondly, the use of the RM implies additional cost in the process of evaluation compared to a pure virtual system. So the panel of users aimed at the time of evaluation in Mixed Reality cycle is largely less important than for a pure virtual system, thus bringing back for us to the problem of statistical validity of evaluation results. Technically, Mixed Reality can also requires important implementation costs (controlled environment, special lightning, image treatment algorithms, localization ...). We can also note the problems related to screening and interactions treatments between the real and virtual objects.

4. Application to ARPH project

4.1. Project presentation

We will apply this method to the complex system ARPH which is a robot assistant used for the remote control of objects by a handicapped person. ARPH is developed for people unable to move and handle objects without assistance. The objective is to give them a minimum of autonomy in their everyday life, whether it is at home or outside.

The development of a complex and innovative technical assistant requires a large spectrum of competences and thus to make collaborating many scientific and technological disciplines (Data processing, EEA, mechanics…) and human ones (psychology, neurosciences…). It is in this context that we are interested in the User Centered Design (UCD). ARPH project led to a prototype actually in evaluation by handicapped users. The design followed a cycle in spiral with participation of the users at the time of the needs expression and during some evaluations.

The objective of this section is to show in what the approach could lead to a product more in adequacy with users' desires and especially more regularly evaluated. We start by presenting what exist, and then we present the constraints which influenced the choices for the design. Then, we finish by illustrating the interest to follow the UCDCS method presented in this paper.

4.2. ARPH system actual state

ARPH (figure 9) is composed of a manipulator arm fixed on a mobile platform making it possible to seize, handle, and activate, whether it is in sight or not, thanks to a directional camera. An ultrasonic belt enables platform to avoid obstacles which are on its way. An on board robot computer supports servers for the management of the principal material components.

Figure 9: ARPH prototype

The system is remotely controllable via a server/customer architecture and a wireless WIFI network. The user interface shown on figure 10 is installed on a distant computer. The user can drive the system using various command modes: manual, camera direction following, target following… ARPH system prototype was evaluated by potential end users in July 2006. The results are actually exploited.

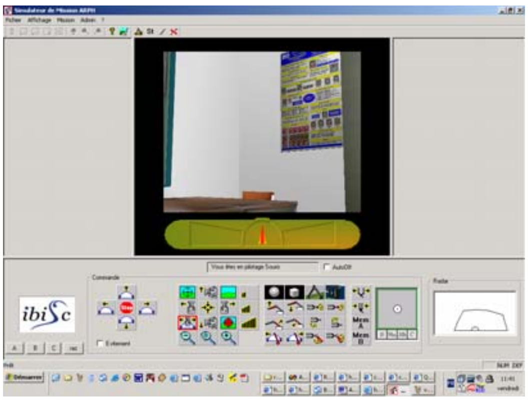

Figure 10: User interface

In parallel, we developed a VR simulator (figure 11) having the same physical characteristics as the real system (field of view for the camera, platform speed, real environment modeled in 3D) as shown on the figure 12.

Figure 11: Simulator overview

Figure 12: Real and virtual camera viewing

Simulator is developed to run on a simple P4 2.0 personal computer, which means with no specific graphical hardware, ensuring us no special hardware is needed for personal home evaluations. It is developed under Windows XP in C++ and use OpenGL libraries. Objects are actually modelised and saved in .obj and .mtl files. Between the simulator development and the taking of the photography, the environment has a bit changed. Even if it's simple to add new objects in the virtual world, it's not necessary. Walls, doors, windows, table and some materials are largely sufficient for a human person to recognize the place and to move in it without any problems.

The user interface is the same for the real and virtual systems. We have, via a training course in collaboration with the university of Rennes, validated the advantage of this simulator for platform approach process and object seizure one (publication in progress). Conclusion report of those evaluations shows that the behavior of the users is overall identical in virtual and real situations (typically, the learning curves are similar). The results show a greater similarity between the two conditions for the moving phase than for the seizure (intellectually much more complex phase) where the user seems a bit disorientated by the simulator. The analysis of the results tends to show that for complex tasks, user is less concentrated with the simulator because of virtual parts and thus less risky situations for material.

When designing simulator, we reached a certain degree of realism (obtained without expensive data-processing equipment, simple software which can be installed on any standard actual PC). Software architecture enables us to easily integrate new virtual environments and its modularity to modify easily such or such component (positioning of the camera and arm, field of view, orientation, obstacles sensors, behavioral algorithms ...).

ARPH software architecture is composed of many components (controlling real or virtual objects). Each component is independent and can run alone. So, it's possible to easily switch control between real and virtual parts because of the common interface.

4.3. Constraints and choices

During the systems designing, we met two great types of constraints to build the two principal functions components, namely the mobility of the platform and the seizure of objects. The first is mainly due to the will to re-use as much as possible products marketed with their inherent advantages: reduction of the cost, use of a product made reliable and maintained by industrial distributor …
However the re-use concept constrained the choice of the solutions until moving away from the concept. It is necessary then to evaluate if the use is preserved. The second type of constraints is related to the difficulty in defining a priori the position of components compared to

the others: arm compared to the mobile base, camera compared to the arm…

VR offers a great freedom, but there are indeed constraints of implementation which it is necessary to take into account in the realization of the simulator. Mobile base and MANUS arm must be modeled just as they are in reality.
Nevertheless, camera and sensors of proximity are for their part completely modifiable being given the increasing number of this type of material proposed to relatively low cost. This being known, it is important to notice that we do not seek to validate each part independently but rather a function of use as for example the seizure of object which can utilize several parts and specifics behavioral algorithms.
The choice of the parts is thus important but the positioning of those the ones compared to the others to satisfy a specific function is almost more important. The process of appropriation [PI1][PI2] of the system by the user depends directly on this choice as showed in the study which we led on this subject [RA1], which the traditional methods of design can solve only at the price of important investments in money and time.

4.4. Cases study

Evaluations on simulator and real prototype show that the manipulator arm is not best placed. Indeed, the arm reachable domain is partly unusable due to the platform obstruction. Secondly, the intersection between the field of vision of the camera and the reachable domain of the arm is limited, inducing a great cognitive effort for users for seizure... Thirdly, object seizing phase during evaluations as explained in a previous paragraph was harder in simulation than in real situation. Thus, we propose to move the arm compared to the mobile platform and the camera using AV in which the manipulator arm is real, the mobile platform and the environment are virtual ones. This case is first studied in the next section.

In seizure evaluation, we observe that the use of the MANUS arm is difficult, inducing shocks, deterioration of the material and stress for the user. In the second studied case, we want to evaluate seizure without worrying about collisions while keeping a real aspect of the environment. To do that, the second studied case uses AR by controlling a virtual arm in a real environment. This case also explains the benefits of AR for training.

4.4.1. Augmented virtuality

We show in this case how to apply the UCDCS starting from an existing and immutable part of the final system: the Manus arm manipulator. Because of perfect dynamic modeling difficulties of the arm manipulator, we rather prefer iterate on a MR plan than on a pure virtual one. In this case, we can deal with the problem for positioning the different part of the system as better as possible.

So, here, the idea is to superimpose on a virtual mobile base evolving in a virtual environment a real arm, MANUS. This case requires to control the real Manus arm and to position a directional camera to film it. This camera must follow the movements of the virtual one to obtain a correct visualization of Manus. The arm is extracted from this video. It is necessary to simplify this phase by adopting suitable lightings and special colored backplanes (green/purple, uniform lighting). The extracted image can then be superimposed on the calculated virtual image.

First, we avoid the difficulties of dynamic realistic modeling of the arm and offer the users a real visualization of the manipulator arm. In the same time, we can modify the position of the arm compared to the platform and the camera by simply moving the camera used to film MANUS.

In this case, the MANUS arm is fixed in a controlled environment and cannot hurt objects like tables, doors or wall. With this solution we don't have to control MANUS arm and real environment collisions. We can concentrate us on seizure functions.

Nevertheless, it appears limits. Indeed, unless developing an expensive system of extraction, we cannot avoid the problems of screenings. Indeed, the arm being superimposed on the virtual image, it will be always in the foreground, what excludes to drive one of its articulations behind an obstacle of the virtual world. For evaluation, we propose to only model the grip to allow for example the seizure of virtual objects.

4.4.2. Augmented reality

Here, we more particularly develop the method proposed on figure 6. During evaluations with end-users, the concept of mobility by the function « mobile platform » was validated. But, it appears difficulties when using embedded manipulator arm, especially because of too simple control mode. Theses evaluations take place on a complete real plan. We thus enter a new design cycle on an MR plan by using the real mobile base and a virtual arm manipulator.

Technically, in this case, we use the real mobile base for moving and the embedded camera to get video of the real environment. Then, we superimpose on the real image a virtual MANUS arm.

First, this mode ensures a perfect realism of moving at the visual and dynamic level. Secondly, by superimposing on the real image a virtual arm, it is possible to handle without risks. Collision detection is ensured in the virtual world.

As we previously specified it, the use of the system requires training. In order to minimize time, it is possible to use the advantages related to AR and especially the visualization of virtual objects. Indeed, it is not necessary to directly superimpose the virtual arm on the real image. We can use effects of transparency to leave the user a better vision of the environment. It is also possible to superimpose for example, only the grip on the real image.

Although Manus is the only manipulator arm currently marketed (thus an obliged choice for our system), it would be interesting to model another kind of manipulator. Another advantage of AR is the possibility to define more easily the ideal tool for handling (which is not inevitably an arm manipulator) and that, without any additional material cost.

The installation of this mode is materially simple (figure 13).

Figure 13: Real environment and virtual arm

However, it is also necessary to prohibit the situations with screenings. We can in certain limits cure this problem in a relatively simple way. Indeed, the experimental phases for the seizure take place in a very controlled environment. Thus, the localization of the robot in this case is rather fine. So, we can, by modeling certain parts of the real environment in the virtual world take into account these screenings. In the same way, the seizure of virtual objects in the real world becomes possible.

4.5. Discussion about software

To design complex system, it is important to have well designed software architecture to ensure reliability of all parts put together and their assure maintenance. When mixing real and virtual parts, it becomes necessary, which is not a simple task as explain in [BS1]. Mixed Reality (MR) applications are currently task specifics and architecture design is not currently well designed, taking into account users, hardware constraints and collaboration. Software developments have to be done by thinking the way of interconnectivity. It must be possible to plug/unplug real/virtual component “codeless”. For example, it is possible to control the real MANUS arm, to get real joint value, then to re-inject these values into the virtual arm and to show the virtual scene. The multiple possibilities offered by MR techniques have to be seriously studied before the implementation of this kind of complex system by using adapted software architecture as for example in EVR@ platform [DO1].

5. Conclusion and prospects

In this article we propose an adaptation of the UCD method in order to answer the specific constraints of complex systems. This approach is based on the traditional “spiral cycle” model on which we add a rapid virtual prototyping dimension with the help of techniques related to VR. The first interest of the approach is to facilitate the design and the evaluation of complex systems. The second one is a direct consequence of the UCDCS method use. As we develop virtual and real prototypes, at the end of the process, we have a real system and a simulator. The last one can be used for training.

Having developed a complex and innovative robotic assistant for disable people by using a traditional cycle of design in spiral, with a participation of the users at time of the needs expression and for evaluations, we were confronted with many limitations. We showed the contribution on two examples exploiting Augmented Reality en Augmented Virtuality to make the system evolve. As we have now a real prototype and a simulator, we are implementing the two cases studied before. It’s then necessary to adapt protocols for experiments which take into account reality, virtuality and/or mixed dimensions.

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