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A TABLETOP-BASED COLLABORATIVE ENVIRONMENT TO ENHANCE DIRECT INTERACTIONS BETWEEN DESIGNERS

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ABSTRACT

In a global product development market, collaboration between team members has become a key factor for the success of product design projects and innovation. Most of the time, such collaborative situations are supported by traditional tools such as paper-based methods or single-user IT tools. Our aim is to enhance direct interactions between users through the IT tools by proposing physical devices dedicated to users' business tasks. The proposed collaborative environment is based on the use of a tabletop technology as an output device and physical devices as input devices. An electronic pen and a Wiimote device have been implemented and combined to design tools and tabletop technology for allowing such direct interactions and enhance design collaborative situations. A specific analysis of designers' activities has been achieved for helping defining the input devices and tests scenarios. The results of these tests are presented and validate the feasibility of such collaborative systems. Due to a lack of precision and appropriateness of the existing prototypes a new generation of physical input devices more dedicated to designers' activities and to combined IT tools must be studied in further work.

KEYWORDS

Collaborative design activities, user interactions, tabletop, physical devices.

1. FROM COLLABORATIVE DESIGN TO 3D USER INTERACTION

In a worldwide context, companies must develop increasingly complex and innovative products in order to remain competitive. Several approaches, methods and tools have been developed for many years, as for example concurrent engineering [29], multi-disciplinary teams, collaborative Information Technology (IT) systems [15]. In such a context, collaboration between team members has become a key factor for the success of product design projects and innovation. Product design process can be considered as a complex technical and social process. Furthermore collaboration is seen as an effective and concrete articulation between designers, involved in a collective action, within the same design objectives [23].

Considering the whole product design process, we focus on collaborative situations involving designers interacting in the same place at the same time. At first, we study creativity sessions occurring in the early design phases of a design project, as an example of innovative and collaborative situations; then we study project reviews occurring later on in the design process, as an example of designers interacting for proposing solutions or controlling their work. In both situations, designers may have different skills and knowledge and interact to exchange their points of view and to take decisions. Despite several research works [42, 2] and the available technologies, such collaborative situations are not well-supported by specific tools in most companies. Moreover creative task are often supported by sketching and thus are based on paper-supported work. IT support is generally limited to one vertical screen, not always enough wide for the stakeholders, and a unique input mode (one mouse and one keyboard), which makes difficult for several designers to act upon the visualized object in an interactive mode.

For example CAD systems are unable to support project reviews meetings and it is difficult for 2 or 3 designers to work together on the same CAD workstation. Designers are focused both on the collaboration and on the actions of the stakeholder that manages the mouse. In this situation they cannot interact directly when they want because another one gets the mouse: this restrains their collaborative activity and their solutions.

The functions delivered by CAD systems or collaborative IT tools supporting design are not necessarily inadequate, but we consider that two fundamentals aspects can be improved: the possible interactions between users and the IT system are limited to a single user; moreover the use of a mouse and a keyboard is not always the best way of interacting with the IT system to achieve a dedicated task. This study builds on the works recently synthesized in Johnson [19]. So far the companies are far from integrating these concepts and techniques, that’s why we propose a very pragmatic study in order to enhance challenges and opportunities for future advances in this field.

The aim of our research is to implement a collaborative environment that proposes direct interactions between all the designers and the 2D or 3D data, using dedicated interactive devices. We try to implement interactive devices that allow designers to behave in a paper-support like mode, with the benefits of a computer-supported environment. The followed approach is based on the use of the tabletop technology combined with physical interface devices. In that sense we propose a new way to interact with a collaborative IT system for design activities.

In the next section, we review works on shared interactive surfaces and tables in linked with the collaborative environment we want to implement. We then present the methods and the technical concerns that lead to the design and to the realization of our prototype. In order to demonstrate the usefulness of our prototype in collaborative design situations, we present the experimentations we have conducted. We continue by discussing results of experimentations. We conclude by reminding main propositions of this paper and by presenting future works.

2. SHARED INTERACTIVE SURFACES AND TABLES: STATE OF THE ART

The shared interface, which allows multiple users to interact simultaneously on the same device, is an old concept, already explored by the end of the eighties at Xerox Park in Palo Alto [36]. Wellner [39] proposed the DigitalDesk, the first tabletop that allows interacting with IT by the way of an interactive table and by the use of physical devices. During fifteen years, these devices such as interactive tables remained rare and often unique [3, 31, 41]. Recently, there have been proposals for marketed interactive multi-touch tables (the Microsoft Surface, the Mitsubishi MERL DiamondTouch, the IntuiFace from IntuiLab [17] or the Ilight from Immersion [16]). But providing such devices is not sufficient to support the interactions between co-located users. Concurrently a lot of interaction styles have been developed using a wide variety of devices (mouse stylus, keyboards, microphone, etc.) and a large variety of interaction techniques (drag and drop, pull-down menus, tabs, collapsible trees, etc.). Recent work on interactive tables and on multi-touch tablets, like the iPhone from Apple, the Lemur from JazzMutant or the Jeff Han's surfaces from his society Perceptive PixeL, really question a foundation of HCI: interaction through a single pointer. The goal of our work is to explore, in the specifically context of collaborative design, the user interaction on a large surface of visualization and with devices offering more than a single pointer.

2.1. Design point of view

During product development process, designers must take technical decisions and choices that constrain the product for all its lifecycle. By the way they affect the achievement of other designers' activities, and later of people in charge of industrialization, manufacturing, delivering, maintaining and recycling the physical product. Decisions are strongly dependent on designers’ activities [20]. Most decisions are taken after collective processes with a lot of interactions between several design stakeholders, involving a repetitive cycle of perception, decision and action [13]. The reality and the impact of the collaboration between designers [23] depend on numerous factors. They must analyze the situation and make decisions based on both knowledge and experience. Designers therefore need powerful interactive tools to complement information transmitted by voice, allowing multiple interactions between them and supporting information exchanges through adequate intermediate objects [6]. This enables formal tacit knowledge to be turned into explicit knowledge.

Collaborative tools have been proposed to support such design interactions and intermediate objects in association with CAD systems: Maher [25] proposes

CSCW (Computer-Supported Collaborative Work) tools, Rosenman [33] proposes multiple views of product functionalities, added to CAD ones. Such tools allow the integration on a shared model of all the components of a complex product in order to validate it during project review meetings. Virtual Reality techniques improve DMU (Digital Mock-Up) to analyze and evaluate product design at different steps of its development [26, 27, 22, 24].

The final aim of the research that we engage is to propose new tools to support these interactions between designers by combining physical devices, input and output devices, allowing multiple users' interactions, and by developing an IT framework based on a multidisciplinary model for design collaboration. In this paper we study only the physical devices dimension. The main objective is to foster multidisciplinary collaboration among designers and to develop new way of interaction between them and taking into account of their differences of culture due to their domain of expertise (design, manufacturing, marketing, sales, etc.). The main restriction deal with the single input and output devices for a synchronous collaboration in the same location: it becomes then difficult for each designer to interact with the objects when he feels it necessary. The second kind of restriction that we intend to solve corresponds to the fact that some specific design tasks may benefit from specific devices use rather than traditional mouse manipulation.

2.2. Related interaction techniques

Our goal is to build a collaborative environment for design that proposes direct interactions between all the designers and the data [32]. Such a tool needs to explore and to integrate three concepts.

Firstly, for collocated collaboration, the case we are dealing with here (it is also true for remote collaboration), large shared-displays such as walls or tables are especially useful. A large surface allows a group of users to work together while providing enough space for personal/private and public spaces. Even if marketed and quite expensive marketed products exist for generic use, several researchers in the tabletop community provide ad-hoc and cheaper solutions for experiment new way of interaction. Prior research in this area has investigated mixed-presence drawing surfaces and tangible interfaces [38]: TIDL, RemoteDT, DiamondSpin, Buffer Framework and the very recent DigiTable and T3.

Secondly, a person naturally acts by watching the space around her/him to gather information and by manipulating physical objects. Those physical objects can be grasped or move. Similarly, some special physical objects can provide people a mean to interact with a computer system as they are used to interact with the world in everyday life using tools. Let us interest in one of the several types of sensing-based interaction: the pen based interaction. Subrahmonia [37] underlines that pen based interaction is still the most convenient form of input in a large number of applications. For example, in the preparation of a first draft of a document, using a pen allows concentrating on content creation. The pen is a socially acceptable form of capturing information in meetings that is quieter than typing and creates minimal visual barrier. Pen is also well adapted for applications that need privacy and that need entering annotations/marking. Most of the time annotations remain informal and are considered as mere supports to a verbal exchange. It is important to consider annotations as complex and composite elements that can play a central role in design co-operation [5]. Today, pen hardware technology is improved in user-interfaces and handwriting recognition algorithms. There are still however, a number of challenges that need to be addressed before pen computing can address the features we listed above from Subrahmonia's work [37] to an acceptable level of user satisfaction. We plan to address, in the following, the user satisfaction working in design using pen interaction on two large shared-displays: a table and a wall. We choose the table and the wall because in collaborative situation of discussion and thinking, they are the more common supports.

Thirdly, the context of design leads us to take into account the assembling of two elements such as CAD parts as it is a very common task in this context. For this task, the user has to manipulate double 6 degrees of freedom at the same time, and classical user interfaces such as the 2D mouse or the keyboard are impractical for this assembly task [8]. On a more general point of view interacting with 3D data is a challenge, particularly well described in [7].

Despite those difficulties, in this paper, we explore the integration of three main concepts: the use of pen based interaction on large shared-displays for 2D user interaction with sketches/drawings and for 3D user interaction with CAD parts.

In the next section we study new types of handling devices (i.e. devices useable with the hand), with the aim of improving both business tasks and collaboration among designers.

3. DEVELOPMENT OF PROTOTYPES IN ORDER TO EXPERIMENT NEW INTERACTION TECHNIQUES

We developed an operational prototype to experiment with two tasks: handling a 2D object and handling a CAD part in the 3 dimensions. Our prototype is based on multiple output displays, wall and tabletop, and on physical input devices.

3.1. Research method

The followed method has been developed previously in order to support the implementation of prototypes that both may validate research work and must answer to users' needs. This method (figure 1) is a combined approach, user-centred and technological, composed of several activities: after an initial definition of the studied domain activity, two parallel but integrated phases are engaged - a user-centred one and a technological one - and finally these two phases merge through a combined evaluation activity then the activity of improvements definition. The prototype is then ready for more industrial tests.

During the user-centred phase, we apply different techniques inspired from ergonomics:

- we first study the professional context of the designers in order to identify, characterize and analyze their activities; here it corresponds to the analysis of collaborative design activities;
- we then define scenarios for future experiments, in order to be able to evaluate the prototypes in a real-like environment; this strategy is due to the fact that research prototypes are often not enough operational to be tested directly into companies;
- and we then proceed with the users tests based on the scenarios.

Concerning the technological phase, it is a traditional research phase:

- a large state of the art and bibliography to evaluate previous work and orient our solutions with the definition of comparison criteria;
- technological choices leading to the design of a prototype and based on a hierarchical matrix; the choice of one technology is defined by taking into account the type of interaction identified during the analysis activity of the user-centred phase;
- and finally the design and the implementation of the prototype and technical tests that must validate that the prototype is operational. The implementation influences the definition of users' scenarios.

3.2. Technical method and hierarchical matrix

Our design process dealt with human-machine interaction specificities such as multi-contact interaction metaphors and styles, with several co-located users, information display and toolboxes. We conducted a design methodology that integrates classical methods of both computer science and product design. In our approach, the key element in the early stage of design of the 2D or 3D user interface consists of identifying the users' major needs, taking into account the users' skills and experience in doing the two targeted tasks. We propose that the design is multidisciplinary integrating both the product designer and software designer, as well as being a participatory approach that also includes the end user. The goal of this process is to design the right interaction technique and the most suitable device.

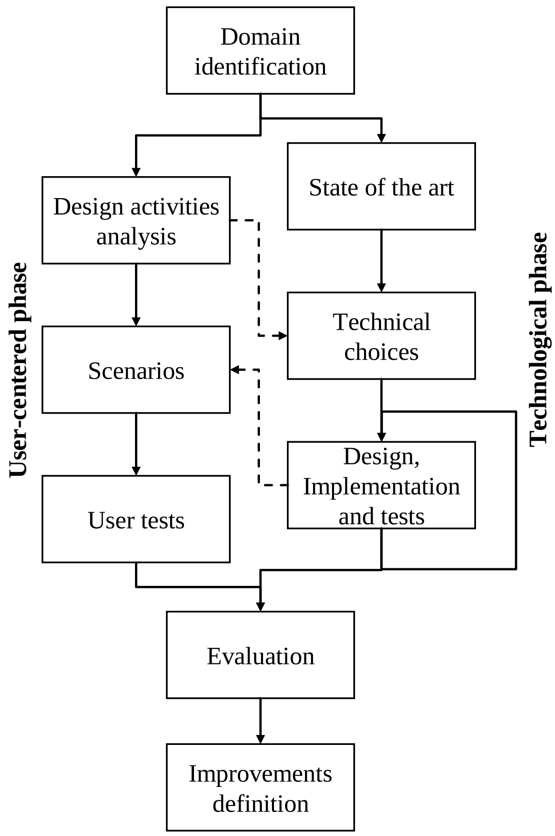

Figure 1 Prototype development activities

We used hierarchical matrix to identify the best solution among all of possible solutions stemmed from state of the art and brainstorming. The hierarchical matrix (table 1) represents the relevance of the solutions in function of the respect of different criteria. We allocated a coefficient valued on the set (1, 2, 3) to each criterion according to what we consider from the most important (high coefficient equal to 3) to the less important (low coefficient equal to 1). The criteria are listed in below by beginning with the most important and ending with the less important. Each criterion is evaluated with a set of values sufficiently discriminating while experimentally assessable:

- “Grasping”: coef. 3, evaluated from 0 to 3;
- “Tiredness for a long use”: coef. 3, evaluated from 0 to 2;
- “Easiness of transmission from one user to another one”, “Intuitive use”, “Cost”, “Difficulty for programming”, “Life length (years)”, “Not very cumbersome”, “To be wireless”: coef. 3, evaluated from 0 to 1;
- “Affordance”: coef.. 2, evaluated from 0 to 3;
- “Optimizing task time”: coef. 1, evaluated from 0 to 1.

At this preliminary stage, all criteria are very generic criteria based on technical and economical aspects as well as human aspects and the easiness of the possible customization of the device.

This matrix allows selecting a variety of devices that must then be evaluated through specific studies according to our context: collaborative design activities, as shown in figure 1. Our final choice is explained in the following section.

Table 1 Devices vs. criteria

Devices / Criteria	Grasping	Tiredness	Trans. easiness	Intuitiveness	Affordance	Cost	Programming	Life length	Not Cumbersome	Wireless	Time improvement	**total**	Functions hierarchy	Selected solutions
Puck	2	0	1	1	0	1	0	>2	1	1	1	26	4	**X**
Pen	3	0	1	1	1	1	0	>2	1	1	1	31	2	**X**
Glove	-	0	0	1	1	1	1	<2	1	1	1	24	6	**X**
Stick	3	0	1	1	1	1	0	>2	1	1	1	31	2	**X**
Bowl	1	1	0	0	0	1	0	>2	0	0	0	16	10	
Dice	0	2	1	0	0	1	1	>2	0	1	0	16	10	
Tactile screen	1	2	1	1	0	1	1	>2	1	1	0	25	5	**X**
Laser	-	2	0	0	0	0	1	<2	0	0	0	18	9	
Wiimote	2	1	1	1	0	1	1	>2	1	1	1	26	4	**X**
Ipod	1	0	1	1	1	1	0	>2	1	1	0	24	6	**X**
Post-it	-	-	1	1	1	1	0	>2	1	1	1	37	1	**X**
Voice	-	2	0	0	-	1	1	>2	1	1	1	28	3	**X**
Compass	0	1	1	1	0	1	0	>2	1	1	1	23	7	
Eye Toy	-	2	0	0	0	1	1	>2	1	0	0	22	8	
Finger	-	2	-	1	1	-	0	>2	1	-	1	37	1	**X**
Tripod	2	0	1	1	1	1	0	>2	1	1	1	28	3	**X**

3.3. Technical concerns

Let us first have a closer look on some design decisions for our prototypes.

3.3.1. First Prototype

The first implemented prototype is based on a platform that includes a video projector and a video camera assembled on a moveable tripod, in order to work on any horizontal flat surface like a table or a desk. This set-up is related to Bricks [12] and the IP Network Design Workbench [21] and used the prototype designed and built in [9]. An intangible graphical representation of data is displayed on the surface of a tabletop. Direct manipulation of the data is enabled by acting with physical tools on the projection space. Eventually, several persons can work together to accomplish a common trade task around the common space that is the surface of the table.

As physical input device we use a pen composed of an infrared diode that allows a Nintendo Wii Remote (Wii) device to identify the position of the cursor on the table and a switch that activates the infrared diode (figures 2 and 3). Note that industrial solutions are available, for example with the Anoto technology (Anoto [1]). Anoto Pen enables digital capture, transfer and processing of handwritten text and drawings, all with pen and paper.

The software associated (i.e. Paint) with the pen device is a 2D image editor that proposes functions that will be used for experimentations described in following.

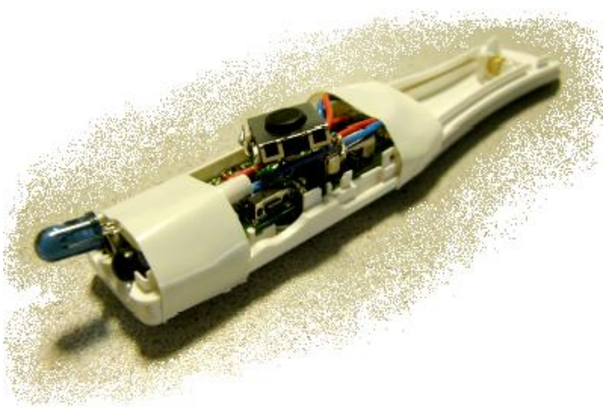

Figure 2 First 2D prototype: pen device version 1

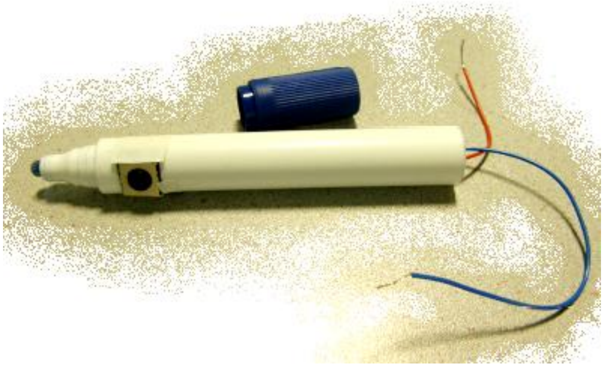

Figure 3 First 2D prototype: pen device version 2

3.3.2. Second Prototype

In the second implemented prototype, we choose for the output interactive surface either the wall of the room and either the surface of a table. Thus, we use set-up of the first one or a video-projector to visualize large CAD part in the 3 dimensions on the wall.

As physical input devices, we use a homemade electronic pen, two Nintendo Wii Remotes and a Nunchuk (Wii) for achieving the whole functions. The use of the Wiimote devices requires specific configuration. First Wiimote device will be used as a receiver and must be placed to look at the screen projected onto the table. Moreover, the angle that will be formed between this device and the screen will have to be of 45 degrees for an optimal reception and its distance will not have to exceed 4 to 5 meters. During its use the field between the Wiimote device and the pen must be kept empty. The second Wiimote device is used as the active device for transmitting user's commands. For the 3D interaction, the pen is limited to a pointer role and for a good quality of the selection recognition it must be used close to the table, under 1 centimetre. Finally, we used a led rail (10 centimetres long) as a base for the Wiimote devices.

The entire prototype is represented in figure 4.

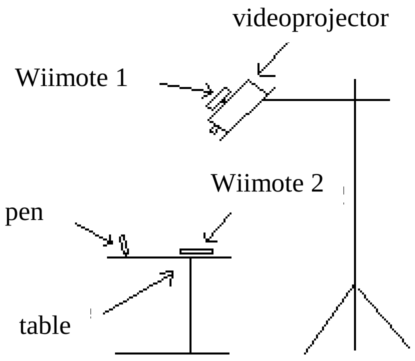

Figure 4 Description of the prototype environment

We emulate Product View from PTC (ProductView), software dedicated to digital mock-up (DMU). By this way the devices emulate the mouse and some keys combinations in order to activate the functions of the DMU software and to achieve the dynamic movements and the sectioning. We developed a second version of the pen where the momentary switch linked to pen pressure (figure 5).

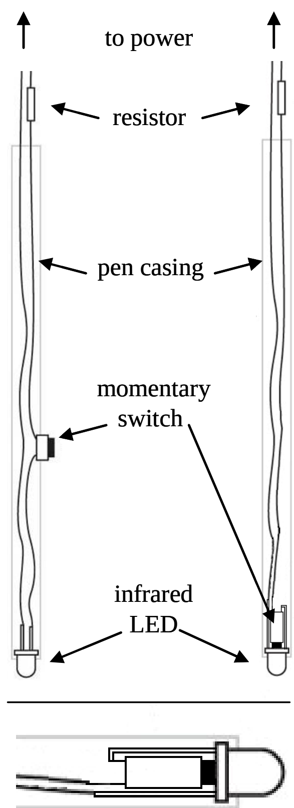

Figure 5 From 2D handling prototype 1 to prototype 2 and zoom on the momentary switch linked to pen pressure

3.3.3. Software used for integration

In the two prototypes, to integrate and allow interaction between hardware and trade software three tools were used:

- the Microsoft .NET Framework 3.5 Service Pack;
- the BlueSoleil software (Bluesoleil [4]), that allows Bluetooth communications between the PC and the wiimotes;
- Smoothboard 1.6 (Smoothboard [35]) is a Wiimote Whiteboard \ Wii Whiteboard [40] freeware that contains a customizable floating toolbar that allows effortless control of your presentations. The built-in annotation feature allows to write and to highlight directly on top of any application or document. You can also create snapshots of the screen automatically with Smoothboard.

4. USER STUDY

4.1. Aim of the user study

The aim of these user-centred experiments is to compare the interaction between the users in a day-to-day activity and the prototype environment. This evaluation is influenced either by the software and the way functions are available, and either by the implemented handling devices.

The objective of these tests is to evaluate the chosen interface by the means of various criteria. We thus intend to identify the advantages and the disadvantages of each handling device for the following qualifications of effectiveness:

- Handiness (many actions, time of the actions, position of people);
- Precision;
- Intuitiveness (time of catch in hand);
- Representativeness of the awaited results;
- Transparency of the object that one holds in his hands. By transparency we mean the faculty to use the interface while doing other actions, e.g. holding a speech.

The scenarios have been constructed to allow this evaluation in order to identify improvements for the handling devices. The used software (ProductView) is commercial software used in collaborative design situations.

The followed method consists in defining a campaign of experiments based on a set of scenarios, combined with two different configurations (working on the table and working on a wall) and with a panel of users. The following table shows the quantitative variables that we will intend to collect.

Table 2 Measured quantitative criteria

Criteria	Measured parameter	Reference value
Velocity for achieving the task	Time	Time obtained with a mouse
Precision	Distance between 3D parts at the end of the task	Precision obtained with a mouse
Richness of marking possibilities	Quantity and readability of the text / symbols / sketches	Marking made by an expert
Level of collaboration	Number of interactions / Time	Number of interactions between experts with a mouse

4.2. The set-up of the user study

15 subjects participated in our user study. They are all researchers in different fields: mathematics, mechanical design and computer scientists. They were not paid. 7 of the volunteers were female and 8 volunteers were male, aged from 22 to 42 years. Their level of study is Msc thesis or PhD thesis years in technical or scientific disciplines. Nearly half of the set of subjects known the DMU software used (ProducView) but are not experts in its use. Subjects are shared out into design tasks experts, 2D/3D software users and innocent users. None of them have used such handling devices previously. This preliminary study was undertaken in order to determine basic tasks that would be representative of collaborative situations in design. Consequently people without any specific knowledge in design or with handling devices should be able to participate to the experiments.

In order to efficiently collect and exploit the results of the user study, we were three persons to organize it. A first person explained the task and conducted the experiments. A second person observed how the users were interacting with sketches, drawings and CAD parts. All the actions achieved by the users will be recorded and timed by the observer. Controls will be visual ones by the observer but also measured for some parameters (time for example). A Video recording was also done for further analysis. A third person was guiding through the questionnaire. The questionnaire was designed to get a qualitative and subjective feedback of our user interfaces. Then, a scenario was defined by a grid for the observer evaluation, an instruction form for the users and a final questionnaire for the users.

An objective of half an hour per subject for achieving the scenarios is defined, including the initial explanations.

4.3. First targeted task: handling a 2D object

The final aim of the first prototype has been deduced from the analysis of designers' activities. Our intent is to propose a new type of interactions between designers involved in a creativity session. During such sessions, designers usually interact on objects represented on sheets of paper: sketches, drawings, images, etc. Their activities consist on drawing, writing or marking. Sometimes they redraw a section of the paper using a bigger scale.

During paper-based sessions, each designer has its own tools (pencil, pen, ruler, rubber, etc) and may use them after or during another designer interaction.

During software-based sessions, each designer has to wait for another designer interaction before taking the devices and then interacts. This is the exact situation that we intend to improve, to be close to paper-based situations.

To simulate direct interactions, we have selected the following functions because of their representativeness; they are the first ones to be used by designers as well as the most often used:

- Visualize images;
- Enlarge / reduce image;
- Draw hand-made sketches;
- Write readable text.

The 2D image editor software associated with the pen device is proposes four basic functions that will be used for testing:

- to open a 2D document,

- to modify the scale of the display with or without selecting a specific zone,
- to create a separated level,
- to draw on this level.

First two functions concern the visualization of the 2D document that is actually a 2D image. The final two functions allow managing marking. For doing so, the computer screen is displayed on a table with a video-projector. The users interact with the 2D handling application using the pen device. The user may open the 2D document in a traditional way, the separated level is automatically created, but the two other functions are selected directly on the table: the location of the emitted point must overlap two displayed boxes representing the functions.

4.4. Second targeted task: handling a CAD part in the 3 dimensions

Usually designers involved in a design project review use a specific tool allowing the analysis and the control of large assemblies of 3D models. During a project review only one operator is able to manipulate the tool. The 3D models are visualized on large vertical screens and all members interact in oral mode between them and with the operator.

During informal design reviews involving few designers, they look on a traditional workstation screen but only one is able to interact with the workstation at a time.

Most common functions concern the visualization and the visual analysis of the assemblies in order to have an overview of the parts made by other teams and to control the coherency of the whole parts definition and position.

As a consequence, the functions to be implemented are:

- Visualize 3D parts and assemblies;
- Make positive / negative zooms, translations and rotations of the 3D scene;
- Translate and/or rotate selected parts with regard to the whole assembly;
- Make dynamic sections of the parts in order to “look inside” the assemblies.

5. EVALUATION OF THE PROTOTYPES

We have achieved the two prototypes and we tested them in very basic situations. These first experiments have to be considered as a cognitive walkthrough based user study [28]. They validate the technical approach but they are not significant enough for evaluating the interest or limitations of our approach in real business situations. Especially, the set of subjects is not enough heterogeneous, they are all familiar with the tasks and all of them had never used such a pen-device. Moreover we were in laboratory conditions. We introduce first the technical tests that validate the prototypes. Then the scenarios for the experiments are described: their elaboration based on a user-centred approach then the results.

5.1. First improvements

Before using the system, a quick calibration step is required: the corners of the screen useful zone on the table are identified with the pen device. This allows the first Wiimote to identify the working zone.

Then the pen and the second Wiimote can be used with both 2D and 3D software. These first tests led to some technical improvements:

- selection of more efficient electronic components: e.g. an infrared led of 950 nm;
- validation of energy consuming: a 1,2V AAA battery;
- replacement of a lateral switch by a contact micro switch (figure 5): it has been selected with a very weak displacement (<1 mm) in order to increase the precision of the contact.

These tests validate also that the whole system technically works and is able to interact with the selected software. Figure 6 illustrates the way the pen is used to add marking to a 2D image.

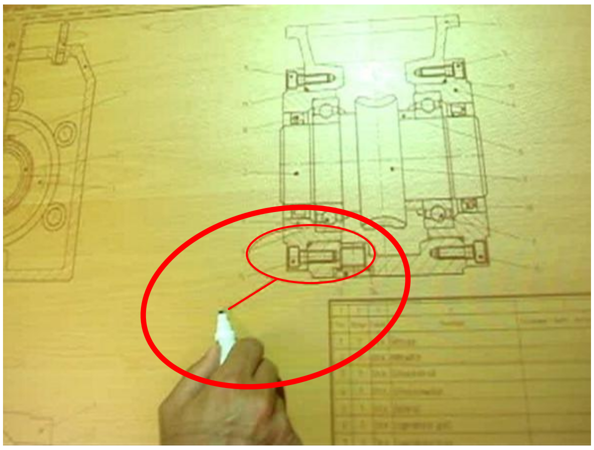

Figure 6 Pen device for marking

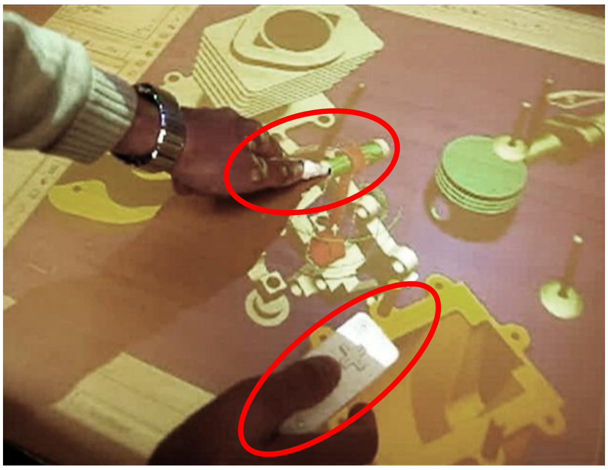

Figure 7 Combined test of pen and Wiimote devices in a 3D situation

In figure 7 the use of the design project review software is verified.

Next step is to evaluate it in business-like situations.

5.2. Experiments

Considering the initial needs that guide the design of the prototypes, three user-centred scenarios have been formalized:

- First scenario: handling of a 3D CAD assembly.
- Second scenario: marking on a 2D document.
- Third scenario: drawing in a creative context.

In the first scenario two users start the exercise with three CAD parts that are not assembled. They are expected to modify their relative positioning in order to approach the ideal positioning of the parts. Each one has at least one part to move. The useful functions are zooming, rotating and translating. The exercise must be achieved in fifteen minutes, this period of time has been defined in order to avoid users from learning about the devices and modify the results of the tests.

This situation (figure 8) allows evaluating the way the users collaborate and work with the two handling devices: the pen and the Wiimote, even if the situation is very close to a mouse use situation. The pen is used to point and select objects or actions and the Wiimote device is used to achieve dynamic movements of the 3D part such as translation, rotation, etc.

The second scenario (figure 9) is dedicated to one single user. A screenshot representing a 3D assembly is shown. The assembly contains many positioning errors and the user has to identify them and to make marking on the screenshot to describe them the most precisely.

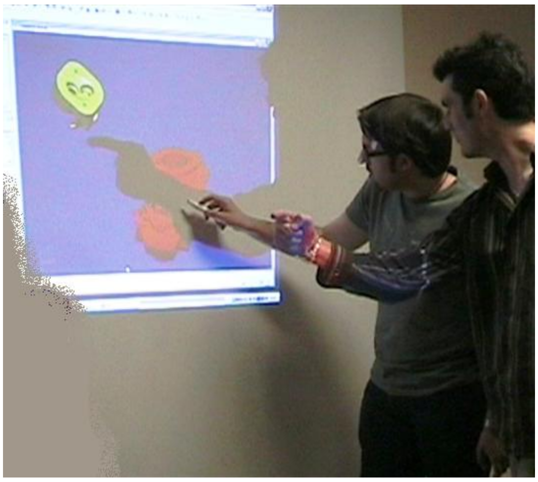

Figure 9 The first scenario on the wall configuration

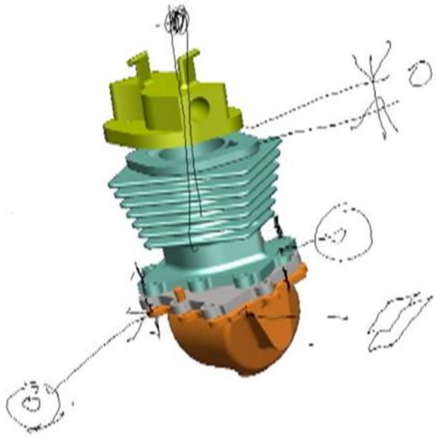

Figure 8 The second scenario: resulting marking

This experiment is focused on the way the pen device is used and especially for writing. It lasts ten minutes maximum.

The third scenario is supposed to take place during a creativity session where two users have to exchange to define a new design. A sketch of a car design is projected onto the screen. The users have to modify the design of the car by erasing and drawing upon it (figure 10). They have different objectives that should generate interactions between them and even conflicts: first user must introduce sharp edges with hard angles and second user must maximize glass surfaces.

This scenario requires also two users but is more focused on the way the pen device helps to formalize ideas through sketches. Only the pen device is used. It lasts five minutes.

Two experts have achieved the scenarios in order to measure initial values and calibrate the future observations.

Each user will have similar environment but two main configurations are tested: horizontal or vertical screen.

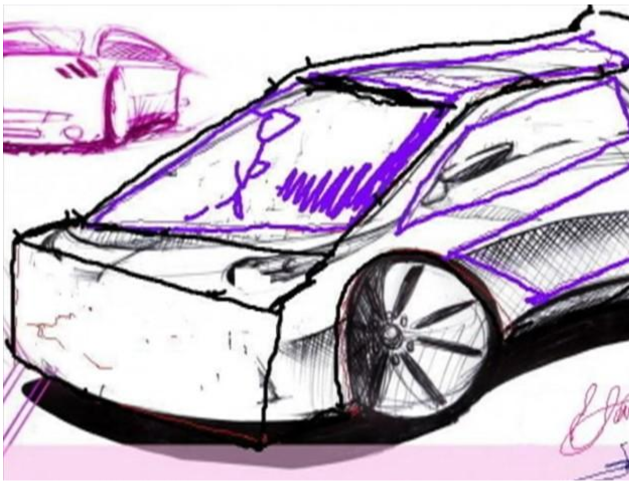

Figure 10 The third scenario: modifying a car sketch

6. RESULTS AND DISCUSSION

The experiments have generated a lot of information resulting from the observations, the measures and the answers of the users' panel to the final questionnaire. We present here general results as the numerous quantities of data are not entirely exploited.

First of all, all the scenarios have been achieved before the time limit. All users were able to manipulate the different handling devices after a very brief description of their use.

Then several statistics have been generated. Concerning the first scenario dedicated to 3D manipulations, nearly 1 user upon 4 only prefers the handling devices to the mouse. This corresponds to the fact that manipulating 3D objects requires strong precision. Moreover the users had to learn how to use the handling device, and they are more expert with mouse use.

Analyzing more deeply these statistics, we established that nearly 90% of the users found that the handling devices easy to understand with 3D manipulations, and 70% that they foster the exchanges between users. The average time of this scenario is 13 minutes (from 8 to 15 minutes) and the time to understand how to use the devices is 2 minutes approximately (between 1 minute minimum and 3 minutes maximum).

Nevertheless they are 56% to say that the handling device will help them for a design project review. And they are only 11% to validate the fact that the handling devices are more precise, more easy-to-use, and quicker to achieve a task than a mouse.

We identify then two key points as possible improvements:

- First, the implemented devices do not require specific learning and they have an added value compared to the mouse for several 3D tasks;
- Second, they suffer from a lack of precision that reduces their added-value in a 3D context.

Furthermore, the scenario was built for a generic validation and several kinds of tasks were defined and tested. We must consider that perhaps different tasks should be associated to different types of devices, each more specialized. This conclusion is also justified by the following results that allow comparing the performances of the handling devices with respect to basic tasks: selection of an object, translation, rotation, positioning and zooming. The positioning as a combination of selections and links between objects is a very technical task and the handling devices facilities have a very bad evaluation (less than 2 upon 6). More basic and non-technical tasks such as selection and zooming have a good evaluation: nearly 4 upon 6. Finally rotation and translation are intermediate tasks considering the technical level asked to the user, and they have also a good evaluation (3.3). Maybe such tasks are already known by most users who knew CAD systems or video games.

Concerning the scenarios 2 and 3 dedicated to 2D interactions, the general ratio is reversed and 3 upon 4 users prefer the pen device than the mouse, arguing that the gestures are more "natural" than using the mouse. This can be explained by the fact that using a pen corresponds to years and years of apprenticeship since little childhood.

More precisely, they are 70% to admit that the pen device is easy to understand. They are also 70% to say that it helps for exchanges between users and 75% that it is helpful for creative sessions or annotations/marking. Finally the pen device seems more precise and simple to 30% of the users. During the tests, users had the feeling that the pen device will work as a traditional pen, but they were surprised by the fact that it was similar but not identical. A traditional pen has a thin and precise lead but the pen device has a larger lead and the location of the numerical projection depends on the angle between the pen device and the table. This point is also a source of improvements for the pen device. Detailed results illustrate better this conclusion by underlining the lack of facilities in the case of marking: the evaluation is only 2.7 upon 6. The zoom task and the draw task were evaluated at 4 and 4.3 upon 6. A commercial pen is certainly the solution for our further experimentations. Using Nintendo Wiimote devices was a way to develop low cost prototypes in order to conduct experiments, see for example Duval [10].

One of the initial objectives was to propose new handling devices that will help collaboration during specific design activities. The origin was the induced curb on collaboration due to the existing keyboard and mouse devices, which cannot be easily shared between people working together on one computer.

We consider the mixed and interactive interfaces/devices, in particular Tangible User Interface (TUI), as systems being able to mitigate these disadvantages. Leaving the paradigm of “virtual reality” where the user is in immersion in the virtual mock-up, we enter in the paradigm of “augmented virtuality” where the user interacts with the virtual mock-up by the way of real (i.e. physical) objects. They make it possible to add new types of handling devices, that is to say devices manipulable by the hand, - dedicated to very dedicated tasks such as design tasks - to the traditional keyboard and mouse, and even to commercial pen and SmartBoard’s products [34] that corresponds to generic collaborative tasks. These new devices allow the user to carry out inputs corresponding to specific business functionalities.

The first results of the presented experiments demonstrate that the implemented handling devices have a real potential for achieving design tasks. Several basic tasks were made successfully by the user panel, and some of them seemed better done with the handling devices than with a mouse (selection, writing, sketching for example). Some others were too specific tasks and show also the limits of our prototypes.

Several improvements are then considered:

- Improving the precision of the pen device, by identifying better components and focusing on the real manipulations of the users.
- Improving the facilities of the software: we used existing software and thus we were obliged to use functions implemented for a mouse and a keyboard; as a consequence we must study similar functions optimized for the type of handling device that we proposed. For example, a rotation is possible dynamically with Product View by acting upon a thin circle around the part, if we replace it by a large circle, located on the part or outside the part, we may expect better results concerning the precision.
- Working on a table or on the wall may result in different perceptions by the users: our experiments did not analyze this point and maybe this influences the results. More dedicated scenarios must be created in order to identify different practices then possible different devices or software functions.
- Designing dedicated devices well adapted to 3D manipulation as well as devices for new specific functions / actions.

In addition, we must exploit more information to evaluate if the learning of the first scenario has an influence on the further scenarios. It is the same for evaluating the impact of the wall or the table during the first scenarios or not.

Finally we used the same handling devices for several tasks. We have to analyze deeper each task and the obtained results to propose for some of them evolutions of the handling devices or even other types of handling devices. For example for a rotation, a handling device that directly indicates the movement should be easier to understand and to manipulate.

7. CONCLUSION AND FUTURE WORK

Our approach, based on the use of a tabletop technology and physical devices aims at proposing a new way of interaction between designers and collaborative design IT tools. The achieved experiments validate this feasibility work by demonstrating the added value of the implemented handling devices compared to standard keyboard and mouse devices for most of basic tasks. Technical tasks show also some limitations: devices are still too generic for very technical tasks and there is a lack of precision for general tasks. So in future work we must improve their precision and the appropriateness of the devices. Further work will focus also on the business activities to improve both software behaviour and devices. So first we have to improve the IT environment in order to propose adequate functions for each handling device. Second, we must characterize more realistic scenarios in relation with the context of use (wall/table, one task/one device, etc) in order to identify the real added value of dedicated physical devices vs. standard devices (mouse, commercial pens…).

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