Tangible Interface for mechanical CAD parts assembly

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Abstract: In this paper, we propose a new kind of tangible interface based on the handling of physical objects that we call "interactors". In our application field concerning the Computer Aided Design (CAD) domain we show that our interactors lead, taking into account assembly constraints from the beginning of the design phase and especially during the phase of CAD model manipulation. In this goal, we define a typology of interactors based on concepts proposed in "Design For Assembly" (DFA) methods. We propose to implement principles suggested by these methods through the use of interactors during the assembly of the CAD parts. So, we will show how the use of our interactors lead the designer to rationalize his CAD model. The interactors enable having a physical perception of the assembly constraints during the "virtual" phase of design on computer. We affirm that the handling of interactors can produce two kinds of results. The first is to give matter for thought on the parts assembly operations. The second can lead to the identification of different assembly solutions for the mechanical system studied.

Key words: Computer Human Interaction, Tangible Interface, Interactor, Design For Assembly, CAD model assembly.

1- Context and problematic

For the last forty years, much research has related to manufacturing steps in order to optimize the design, reduce cost and pre-market times and increase quality [1]. The real need is during the design phase, in order to anticipate as soon as possible all product constraints. So, at the beginning of the 80's, methods and tools referred to the generic term of "Design for X" was created in order to include the various aspects of the product (manufacture, recycling, maintenance, quality ...) from the design phase. Among these works, the methods called "Design for Assembly'" or "DFA" [2] were developed to help the designers in their analysis of the product under development by providing assessment criteria for assembly. These methods follow several attempts of formalization in various assembly guides, the constraints and the rules concerning this activity.

We can notice that the development of the methods dedicated to the rationalization of the activity of assembly is relatively recent compared to the other activities of manufacture such as machining, forging, and moulding. This point can be explained by this paradox: first, it is often thought that the human is familiar with the assembly without having a specific training (certain educational toys are even based on this activity). Therefore why try to optimize the assembly whereas the human seems to adapt very quickly to this activity? Second, it is thought that the "expert" of assembly process operates in an instinctive way and that one cannot formulate his "know how" which is mobilized in the action.

The assembly activity is difficult to formalise due to the diversity and the complexity of the operations and the tacit character of mobilised knowledge. However, this activity is one of the significant steps of manufacture. Cost assembly accounts for 30 to 40% of the global manufacturing cost of a product and approximately 30% of the investments in process resources for the companies [3].

Recent works addressed to the problem of assembly and disassembly of product [4] and flexible parts [5]. These researches are mainly focused on the development of original methods and tools, which can generate all feasible disassembly sequences of a product both from geometric and technological points of views. In this paper, our aim is not to study the sequencing aspects but rather to focus on the part handling, grasping, and insertion aspects. We think that studies concerning of the sequencing processes and the operations aspects are complementary approaches of the assembly problematic.

Moreover, studies and examples of various industrial cases [6] show that the designer in his environment within the engineering and design department cannot always rationalize his own creation. In the same way, we notice that the environments proposed by the traditional CAD software do not really allow a true immersion. In this context, the designer cannot take care of the assembly operation constraints. Indeed, the product CAD model composed of several parts can be easily visualized, handled and assembled in a virtual way by using the mouse and the various software functionalities often proposed by icons and drop down menus. Thus, the assembly of parts in CAD environment is relatively "simple'" to achieve with traditional operations such as rotations, translations and settings in positions by constraints (coaxial, parallel, perpendicular, etc). Unfortunately, these functionalities suggested by the software do not take into account the real difficulty of the assembly operations.

The real constraints (such as difficulties of setting in relative position of two parts before fixing or the difficulties of inserting one part with regard to the others related to the problems of gripping, inaccessibility or collisions of the parts, etc.) are masked by the functionalities existing in the CAD software.

Thus, the current CAD software and the associated peripherals (mouse, track ball, etc.) do not allow the designer to take into account of constraints which are more or less subjective concerning the difficulties of the assembly of certain parts. So this situation leads to the proposal of products which are sometimes very expensive in terms of assembly, problem areas on the lines of assemblies, downtime, etc.

However, it is precisely at design phase time that one can obtain real product profit because 80% of the costs depends on the decision and the choices made at the time of this strategic phase.

2- Design For Assembly (DFA) method

In this section, we propose a general description of the Design For Assembly (DFA) methods. Others works are available in the literature [7] [8] for a more detailed presentation of DFA methods.

The main objective of DFA methods is to propose assessment criteria in order to evaluate the assembly difficulties of a product during the design phase. These methods are often proposed in a software environment which calculates a coefficient of "*assemblability*" of the proposed product. This coefficient is based on the description of the main operations (grasping, handling, insertion…) concerning the product's parts assembly.

During a DFA analysis, a description of the product's part is required to achieve this evaluation. In the DFA software [2], the user must provide a number of required data following several steps:

Step 1: Listing of the product parts

Step 2: Description of the assembly operations including the securing method used (screwing, snapping, riveting…) and the extra operation required (greasing, surface cleaning...)

Step 3: Check of the "minimum part criteria". The aim of this step is to reduce the number of parts by questioning the user on the usefulness of each product part.

Step 4: Description of the envelope dimensions of each part. In DFA software, parts can be described as basis forms: disc, cylinder, plate, beam, and parallelepiped.

Step 5: Definition of symmetry axes of each part.

Step 6: Definition of handling and insertion difficulties. During this step, the user describes the product and identifies the parts handling difficulties: nest tangle, difficult grasp, flexible, tweezers, bulky… and the insertion difficulties: access, view, alignment, resistance …

Step 7: Definition of distances between the assembly operator and parts (or assembly tools).

We can notice that DFA method proposes several assessment criteria to anticipate the assembly operations from the design process. Some subjective difficulties can be identified and evaluated using these concepts and criteria. In DFA analysis physical constraints of assembly operations which are often forgotten by designers during the "creative" phase of design.

We propose to apply these DFA concepts and criteria through the use of a "tangible user interface" based on the handling of "interactors". In the following section, we propose a state of the art of existing systems and then our proposition of "tangible user interface" dedicated to the CAD parts assembly.

3- The Tangible User Interface

As we said before, the use of tools based on the visualization of 3D object cannot always allow anticipation of assembly difficulties. This software is "too assisted" and produce "virtual'" results. Beyond the cognitive concept, the scientific community agrees in say that the input device, such as mouse and keyboard, are clearly limited. Today, it is said that new input devices should be created, so as to allow the visualisation for three-dimensional scenes.

Historically, the first systems of interaction between humans and computers appeared at the beginning of the 1960's. One of the first was the Sketchpad [9], the purpose of which was to make it possible for user to interact in a direct way with the software interface using an optical pen. This system, just like the current systems "mouse and keyboard'" are clearly limited by the interface of visualization, the screen, and by a space of interaction in two dimensions. The traditional peripherals logically evolved towards the 3D mouse and joystick systems which have had limited success. Their uses create a considerable cognitive difference between the action instigated by the mouse and the result in the three-dimensional numerical scene.

To palliate these disadvantages, two currents have emerged: work on visualization (Head Mount Data, panoramic screen, workbench) to strive for the "mixed reality" [10] and the "tangible user interfaces" [11] quoted in [12].

As [13], we think that the systems directed towards visualization, included under the heading "Virtual Reality", require complex haptic interfaces in their realization for an interaction of quality with the digital model.

Tangible interfaces, from Latin *tangibilis*: to touch, seek to make intuitive interfaces whose finality is to couple reality and the numerical data with an aim of simplifying the interaction. For that, tangible interface is based on the use of real objects which allow a representation of the data and a physical control of numerical information [14].

So by joining the idea developed in [14], we think that the tangible interfaces can be bring innovation into assembly and visualization of virtual objects. With real objects, handling is simple but nevertheless can lead to identification of assembly difficulties such as symmetry, occlusions, and positioning of the parts (see section 5).

We think that the handling of physical objects makes it possible to return the product assembly phase to the real world and leads the designer to raise questions in a "natural"' way by carrying out the gestures related to the assembly. Moreover, it is now admitted [15], [16] that the use of real objects for displacements and the control of the virtual objects is more powerful than the traditional systems (Virtual Reality, 3D Mouse).

4- Proposition of Tangible User interface for assembly in CAD: ESKUA

4.1 – Description of Tangible User Interface

A tangible interface is made up mainly of two parts: the tangible part (to allow the interaction) and visualization (the feedback of handling). Ullmer and Ishii use the term "artifact"' to designate the physical objects of their tangible interfaces [17]. The artifacts are at the same time an input device and an output device. Handling of artifacts modifies the virtual objects (input device). By casting one's eye over the artifacts information regarding position, orientation, etc. is obtained by the user in contrast to usage of a 3D mouse.

In our application, we will use the term "interactor" to define our artifacts because they take an active part as "actor" in the interaction process.

After we describe the component of a tangible interface, we discuss specific application. The examples closest to our work are the "Active Cubes" [18], the system developed at Laboratory MERL [19], and the model of Segal [20], [21] (see figures 1-3).

Fig. 1: **The "Active Cubes" (taken from [16])**

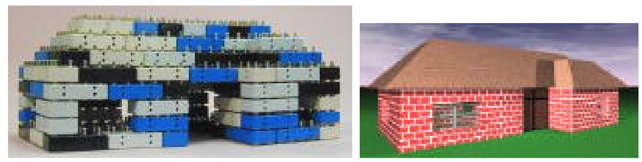

Fig. 2: **The MERL project (taken from [19])**

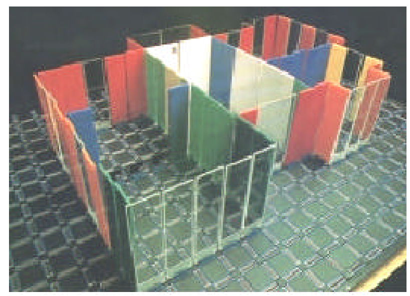

Fig. 3: **The model of Segal (taken from [20])**

All these applications make it possible to assemble artifacts face to face by electronic connection. Moreover, except for the Active Cubes, applications are not in real time. The assembly of the interactors with connectors does not seem relevant to us, because it induces too much restriction. Indeed, user can make face to face interactor assembly (without positioning fixing and orientation problems). Thus all these tangible interfaces are neither designed and nor suited for handling and assembly.

4.2 – ESKUA: a new platform for CAD assembly

ESKUA is a tangible user interface that we propose to solve handling problems. This platform will make it possible for the designer to carry out the assembly of product CAD parts. Our goal is to propose to the designer a working environment which enables him to be confronted with assembly constraints which are currently masked by existing CAD software functionalities. For example, positioning difficulties for two parts before fixing or parts insertion difficulties such as inaccessibility or collisions will be potentially identifiable by the designer during his handling.

ESKUA associates each real object with one or more virtual objects (one or more CAD parts), see figure 4. Our artifacts (or *interactor*) can be defined as "figurative", because their forms are primitive like cylinder or parallelepipeds and they symbolize for the user more complex virtual objects.

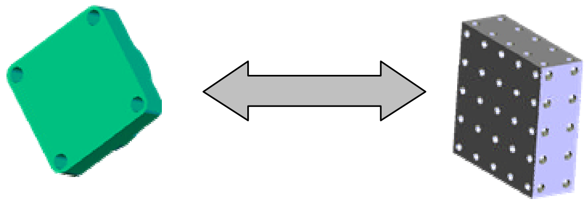

Fig. 4: **Association between part and interactor**

The actions that the user will carry out on tangible objects (displacement, assembly, rotation, etc.) will be reproduced in 3D on the display screen. The capture of the position and the orientation of the artifact in the assembly is based on a system of video capture. Its low cost and its upgrading capacity (a number of cameras, choice of artifact shapes, identification with colours) seem to us very interesting assets. For motion capture, we intend to use model-based systems. In [22], the authors use a hand model in order to capture the hand movements. Given a hand model in a starting pose and an input image, a model-based algorithm will make the model gradually converge to a final hand pose. We want to adapt this approach in our system. The interacteurs do not lose their forms contrary to the hand, but they are move in the space. Thus, the differences between two captured images are the translation motion (left/right, front/back) and rotations. However, it does not provide enough information to get the orientation of the interacteur. For example: a rotation of 90 degrees between two captured image is not visible. To adapt this technique for interacteurs, we will use piercing as a texture to capture more information. Finally, we will use marks, by drawing symbols on each face, in order to recognize easily faces and their orientations. After we choose the way to interact, we must create the most important part of a Tangible User Interface: the artifact.

To bring the ESKUA user closer to the real activity done by the fitter, we propose several clamping systems which are representative of the various existing technical solutions. For that, we propose various sizes and types of fastener like nuts, screws, studs, pins, etc (see figure 5).

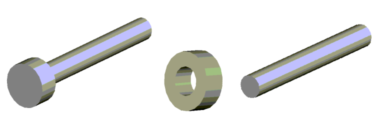

Fig. 5: **Examples of interactor: screw, nut, pin**

The interactors symbolizing the actual parts are bored in several places (see figure 6) in order to allow their assembly by the preceding fastener.

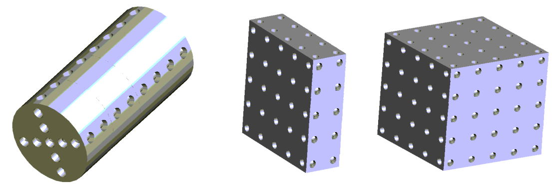

Fig. 6: **Examples of interactor: cylinder, plate, cube**

With ESKUA, the designer can assemble by allotting one type of interactor to one or more CAD parts, and handle these physical objects to carry out the assembly of the product. So the user is confronted with real assembly operation constraints such as parts positioning difficulties or maintaining element in a joint position. It is possible to add certain elements to interactor such as guideway, alignment, etc. We call this element "graft" (see figure 7).

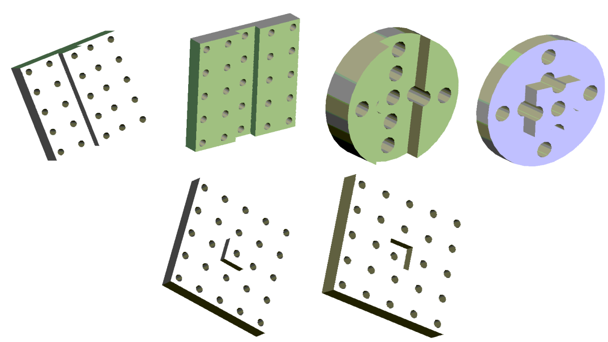

Fig. 7: **Examples of « graft » used in ESKUA**

We use the term graft because the user can add to an interactor a surface provided by guide way or alignment in the aim to modify assembly (figure 4). The addition of graft makes it possible to limit the number of interactor and to offer several assembly solutions.

The DFA methods also enabled us to restrict the interactors to two forms: parallelepipeds and cylinders. In addition, several interactors assembled together can represent certain complex parts. To refine the user perception with respect to the interactor, we have created three sizes for each family: small, medium, large. The goal of this scale is to make it possible for the user to have a visual reference mark (based on the form and the colour) increased by adding volume.

5- Example of application

In order to illustrate the concepts suggested by the use of the interactors, we propose to study the assembly of a clevis mounting on a hydraulic jack (see figure 8).

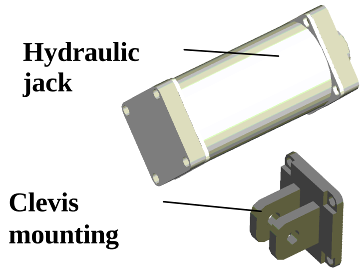

Fig. 8: **Hydraulic jack and clevis mounting CAD parts**

5.1 – Assembly in a CAD software environment

To assemble the clevis mounting on the hydraulic jack, the designer in a CAD software environment using the keyboard and the mouse will be able to follow the step described below:

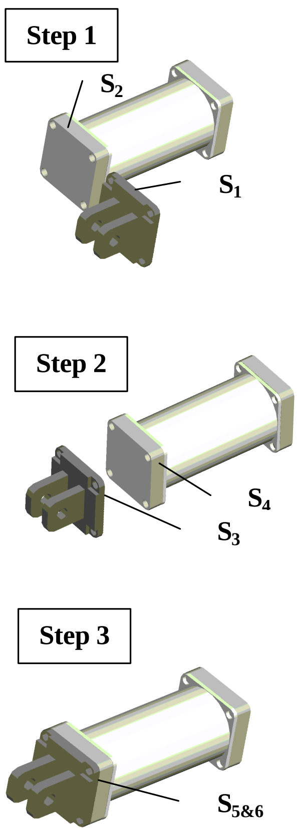

Fig. 9: **Assembly operations for CAD parts**

Step 1

Mouse selection of S_1 surface of the clevis mounting
Mouse selection of S_2 surface of the hydraulic jack
Mouse selection of the "coplanar" action

Step 2

Mouse selection of S_3 surface of the clevis mounting
Mouse selection of S_4 surface of the hydraulic jack
Mouse selection of the "coplanar" action

Step 3

Mouse selection of S_5 surface of the clevis mounting
Mouse selection of S_6 surface of the hydraulic jack
Mouse selection of the "joining" action

Step 4

Selection of the 4 screws
Define position with the "coaxial" action between the screws and drillings
Insertion of the screws by selection of the surfaces and the "joining" action

In four steps, the designer will have carried out his assembly without any difficulty. In this case, we are very far from reality because there is no reflexion on the operational difficulties of parts positioning and fixing.

5.2 – Assembly with the use of "interactors" integrated in CAD software

We propose the following scenario with our interactor to assemble the same product.

Grab with your hand the first parallelepiped interactor I_1
Association is made between I_1 and the clevis mounting part
Positioning I_1 on the platform

Grab with the hand of the second parallelepiped interactor I_2
Association is made between I_2 and hydraulic jack part
Grab with your right hand the interactor I_1 and with the left the interactor I_2

Positioning I_1 in regard to I_2
Hold I_1 and I_2 in one hand while inserting screws into drillings with the other hand

During these operations, the user can taking to account assembly difficulties such as parts positioning and holding due to surface/surface contact between the clevis mounting and the hydraulic jack parts. In this case, the user can identify a problem immediately, and propose a new assembly solution for the clevis mounting. For example, a first proposition (see figure 1 left) is to propose fastener elements such as pins to replace two screws in order to facilitate the positioning. Also, another proposition is to modify the design of the parts in order to create a "mortise and tenon" joint (see figure 1 right).

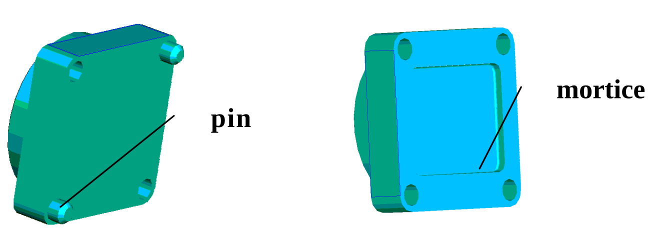

Fig. 10: **New design for the clevis mounting part**

In this case, the user is able to use "interactors" with the corresponding graft to validate the new proposed solutions.

6- Conclusions

Through this work, we propose a new tangible interface that can be integrated in the CAD software environment. Our aim is not to replace the mouse and the keyboard but to assist them for certain design activities and in particular for the assembly operations.

Our interactor makes it possible for the designer to carry out assembly simulation while enabling him to immediately identify difficulties, and to modify parts design with an aim at simplifying assembly.

We think that this type of interface can provide user decision-making support, taking into account assembly production constraints, when technological choices are made in design phase.

On the other hand, it should be stressed that new solutions to assembly simplification must be made in an integrated design environment where each actor shares his point of view and validates his own criteria in design process.

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