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DIGITAL FREE-HAND SKETCHING IN 3D – A TOOL FOR EARLY DESIGN PHASES

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Abstract

Today's CAD systems do not support the creative process of concept development sufficiently. Many designers support themselves with classical handmade sketches before and also during the work with CAD. Sketches can illustrate abstract, indistinct and incomplete information, which corresponds to the mental model of creative thinking. In contrast, modern CAD systems offer the possibility to generate and manipulate three-dimensional objects. In order to unite the advantages of handmade sketches and 3D-CAD in one system, a first prototype of a digital sketching tool was developed. Using Virtual Reality technologies this tool enables an intuitive, creative sketching in 3D. First experiences with the system supply numerous suggestions for advancement, as well as for the integration of the sketching tool into future CAD systems.

Keywords: sketching, man-machine interaction, early phases of design, psychology of creativity, virtual reality

1. Introduction

The Virtual Reality technology basically aims at the representation of virtual objects close to reality and the intuitive interaction with the virtual objects. In order to evaluate the properties of products even before their (mostly physical) realization, Virtual Reality is a good choice for the representation of digital Mock-ups. This technology can supply much greater benefit for product development, if one considers that by the help of this technology, objects, or more general, information can be represented and made accessible, although such objects do not exist in reality.

The mental models that are created and manipulated in a designer's mind during product development are partly not comparable to perception of real objects. This is particularly the case in the early phases of a design process. The information, which is present in the mental models of these phases, is often vague, incomplete, abstract and even irrational. Furthermore these models may be rapidly manipulated and thus a multiplicity of variants is produced and evaluated. In the early phases designers therefore frequently use sketches to visualize their ideas, since CAD systems cannot represent such product information. However, it might be desirable, if sketches could be fully integrated into the flow of digital information processing within product development. On the one hand indistinct and abstract product information could be managed by EDM systems, on the other hand an even greater use would be expected by the functional integration of these information into a comprehensive product model. Elements of a precise CAD model could be linked with the indistinct information of the sketch. A completely new procedure during concept development could be possible that is far more oriented at the thought process of the developer itself.

In a cooperative project of the institute for product development (TU Munich) and the group "knowing-thinking-acting" (TU Dresden) the product representations, which are used in the phases of the task clarification and concept development, were empirically examined. Based on these findings requirements for digital tools for product modelling in these phases were derived. A prototype sketching tool, which fulfils these requirements, was realized by the help of Virtual Reality.

2. Requirements on future sketching tools

Designing is an extremely demanding activity, which consists of creative problem solving processes and routine activities. The faultless processing of routine activities is certainly an important precondition for the avoidance of unnecessary costs and time delays in the development process. However the quality of handling the creative processes determines significantly the quality of the solution itself. Hence, the developer must be supported especially here. But the available CAD systems do not support this at the moment. A survey among designers of different enterprises showed that hand made sketches still play a crucial role during the development process [1]. More than half of the designers indicated that they frequently use hand made sketches at least before the use of CAD. Also while working on CAD about 35% of the designer use freehand sketches frequently or always (Figure 1). Over 90% indicated that the development of new solutions during conceptual design is a primary reason for the use of sketches. This confirms the assumption that sketches possess characteristics, which support creative processes better than CAD or at least reasonably supplement the work with CAD.

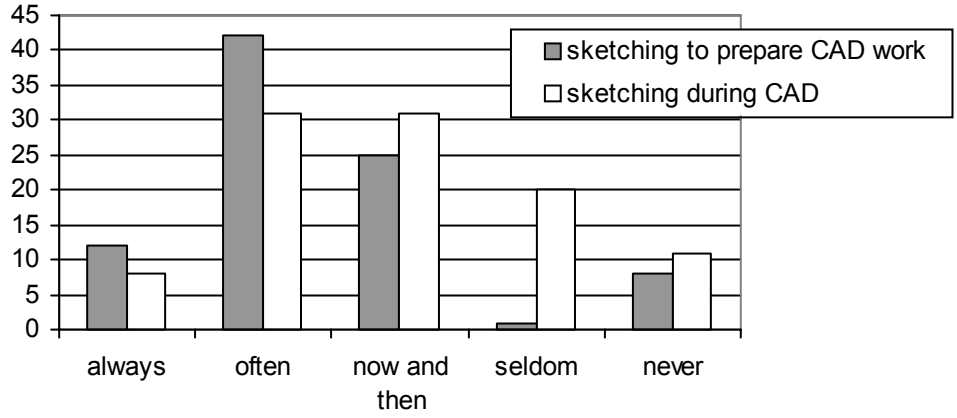

Figure 1. Frequency of use of sketches in CAD work (percentage of subjects, N=75)

In order to examine this, creative processes of thought have to be regarded. The ability for abstracting and concretizing can surely be seen as central mechanisms of creative thinking [2]. For example the term screw is transformed by abstraction to the term connective element, which becomes in turn by concretizing a rivet or a welding seam. Combining the emerging elements, completely new solutions can be produced or existing solutions can be at least varied. Findings regarding the mental capacity of human beings show why such processes cannot run without an exterior medium. Within the short-term memory information can be divided, changed and linked with one another. On average only seven independent information units can be kept conscious at the same time [3]. Even strongly abstracted technical systems usually exceed this complexity limit. Therefore designers help themselves

with external representation media to record new information in order to relieve the short-term memory. If necessary these information can be taken in and processed again.

Thus product representations in product development are not only used to fix the final result of a creative thought process, but rather to accompany this process as a permanent memory buffer of the current state of development. This indicates some requirements on the character of such a medium.

Basically, a creativity enforcing medium has to able to display the mental model of the developer in all forms that exist during the think process. Considering that creative processes are based on abstraction and concretion, consequently a medium also has to display abstract information. If an abstract mental model has to be concretisized to be displayed, then exactly this process utilizes the valuable resources in short-time-memory that should be relieved. Hence, this interrupts the creative process of thinking.

If one regards free-hand sketches, which are used when developing solutions, it shows why this medium is especially suitable for the representation of abstract mental models. The range of kinds of information, which is contained in a conceptual sketch, can be far beyond those of a corresponding CAD model [4]. Thus geometrical definitions with different degrees of abstraction can be contained in sketches. Vague specifications of form and position of an element are illustrated by grubby, weak (sometimes multiply drawn) lines (Fig. 2).

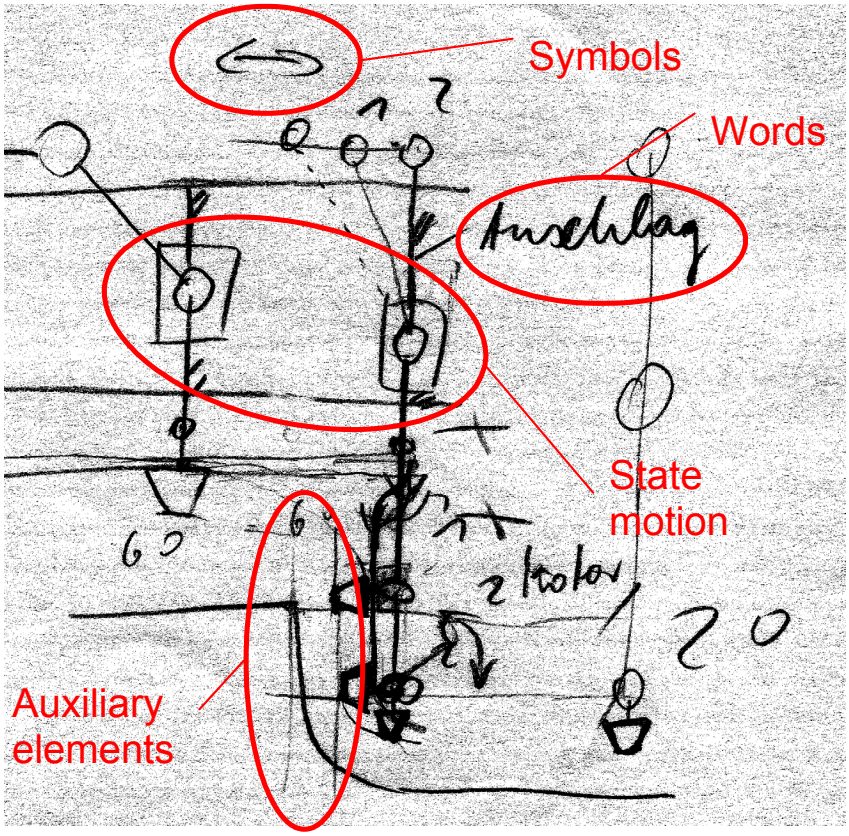

Figure 2. Sample of a free hand sketch

The abstract predefinition represents a multitude of concrete shapes that the element may result in. Concrete predefinitions however are marked by exact, intense lines. Both, abstract and concrete predefinitions could be present in a sketch at the same time. Apart from pure geometrical information sketches can also contain functional definitions on a high degree of abstraction. Kinematic properties of a system are often displayed by motion lines or the

illustration of different states. Symbol-like elements of a sketch can be considered as abstract placeholders for more complex information content. For example dots are used to display joints. Arrows show the degrees of freedom of joints. In this context terms are predefinitions on the highest level of abstraction that is possible. Inserting the term "bedstop" does not determine the later realisation of this element. The possible variety of solutions that is hidden behind that term is not restricted but nevertheless the element correlates geometrically and functionally with the other elements of the sketch by the position of the written word in the sketch.

Besides the type of elements that are sketched also the motion of the designer's hand is remarkable [5]. Often "test-acting" can be observed in which the sketching motion is probed with the pencil a few millimetres above the paper. The direction of the motion is varied several times before the pencil is put down to the paper and the line is really drawn. In doing so several solution variants can be tested within seconds. Even if no line is drawn and the sketch is only regarded, the pencil is used to point at elements. So the eye is guided across the sheet and possibly the imagination of new or altered elements of the sketch is supported. As soon as the developer decides to change something, this element can be drawn immediately as the pencil is already at the right position.

In conclusion the process of sketching with pencil and paper can be seen as a flowing process for solution development, in which definitions are made, examined and varied in shortest time. The individual process steps can smoothly merge, since the usage of the medium does not require an interruption of the process of creative thinking. The information widely complies with the mental model; an abstract and indistinct idea does not need to be concretized only for making it presentable.

Contrary to sketches CAD-systems only support the definition of exact elements, which must be placed accurately in the modelling space. Diffuse mental models have to be translated into exact geometry to be fixed. Also the usage of symbolic and conceptual elements is supported only insufficiently by CAD-systems. The component of hand motion gets lost as well, at least if the designer works with mouse and display. Even the usage of sketch-pads only partially allows procedures like sketching with paper and pencil. Pointing at single elements of the model and testing of variants in fact is possible, but when an element actually needs to be defined, this does not happen by a drawing motion. Since CAD is a vector-based application, the developer has to "leave" the sketch in order to define geometry by clicking menu-items and entering numerical values.

However, CAD also offers some advantages in contradiction to the classical hand made sketch. The most important advantage probably is the spatiality of the CAD models. Although spatial objects can be drawn perspectively on sketches such objects cannot be rotated; there is only one viewpoint available. Furthermore, a digital medium such as CAD permits several opportunities for manipulation of elements. Parts of a CAD model can be duplicated, moved or scaled. A future sketching tool should combine the creativity-supporting characteristics of sketches with the advantages of digital system environments. In the following a prototype of a digital sketching tool is presented that was developed at the Institute for Product Development of the Technische Universität München. By using Virtual Reality, the advantages of hand-made sketches are combined with real thee-dimensionality.

3. The 3D-sketching tool

On the basis of the insight into the use of free-hand sketches, a first prototype of a digital 3D-sketching tool was developed at the institute of product development. This prototype allows drawing 3-dimensional free-hand sketches in space. Similarly to sketching on paper only lines are produced. These lines are stored internally as a "voxel cloud", which corresponds to a pixel graphic in analogy to a 2D-sketchpad. This is deliberately different from surface or volume-based models in order to retain the specific characteristics of the paper sketch in 3D. The free-hand line as the basic design element delivers complete freedom concerning illustration in order to fix abstract, indistinct and incomplete information.

A 3D-sketching tool only makes sense if the sketch can be produced intuitively in space and can be also represented in 3D. In order to attain this goal, Virtual Reality technologies were used for input of the sketches and for visual output. For input as well as for output, several VR-devices are possible. Basically an input-tool (for example a pencil) needs to be moved in space. As soon as the input-mode is activated, a free-hand curve is generated according to the movement of the input-tool in space. Besides pencil-like input-tools with or without force-feedback possibility it is considerable to record gestures of the user by means of a data-glove. This may turn the fingertip into a 3D-pencil. All procedures have in common that the position of the "tip" of the pencil in space has to be tracked. For output a large variety of possibilities exists as well: head-mounted-displays, simple desktop-VR working environments, projection tables and caves can be considered.

The prototype was realized with desktop-VR components both for input and output in order to demonstrate the feasibility of a 3D-sketching tool. In this way it is possible to integrate the sketching tool into the common working environment of designers. Basis of the prototype is a PC-based high-quality graphics workstation (Fujitsu-Siemens Celsius 460) with a 21-inch CRT monitor. The stereo view is realized by using an infrared emitter and shutter glasses.

Software-base for the prototype of the 3D-sketching tool is World Tool Kit 9 by Sense8. This software is run on Windows NT 4.0. The integration of the Phantom Desktop was realized with Ghost SDK, a developer kit that is shipped with the Phantom. Using the Microsoft Visual C++ 6.0 developer studio the 3D-sketching tool could be implemented.

The force-feedback device "Phantom Desktop" is used for the input of the sketch in space. This device has a pencil-like grasp with a button. When the button is pressed, one can create 3-dimensional lines at the current position of the input device. Moving the sketch in space is also done by the help of the Phantom Desktop. As it can be used as a 6-dimensional input device, panning, zooming and rotating can be done in a very intuitive way. Because the Phantom Desktop only has one button, additionally a key on the keyboard has to be pressed to switch from the sketching mode to the moving mode. In future, an input device with more than one button might be suitable.

On the output side, several improvements have been made compared to the former version of the sketcher [6]. Before, the Phantom Desktop was placed besides the monitor just like a usual computer mouse. The 3D-sketches made with this configuration often did not look like the users expected them to be. So a solution needed to be developed in order to merge action- and perception-space. The lines should be displayed exactly at the point where they were created. This problem was solved by the use of a semi-transparent mirror. The mirrored image of the 3D-sketch seems to be underneath the mirror. As the Phantom Desktop is positioned exactly there, the user gets the imagination of acting directly within the 3D-sketch (Fig. 3). This explicitly improves the quality of the 3D-sketches. Having brought the virtual 3D-sketch

into the real workspace (hand, grasp of the Phantom Desktop), this is an application of Augmented Reality.

Figure 3. The 3D sketching tool

The characteristics of the lines that build the sketch can be changed in a menu. This menu consists of a virtual plane that is force-feedback supported. By touching the "icons" on that plane, the colour and the thickness of the lines can be changed. A "friction" effect can be enabled that simulates the contact forces between paper and pencil. The menu is shown in Figure 4. Force feedback could be used to create a haptic snap function to support the user in meeting the ends of existing lines with the cursor. This feature is planed to be implemented in the next version.

Another feature that is already integrated in the prototype of the 3D-sketching tool is the adjustment of the representation of the sketch to the user's angle of view. By the help of a head-tracking system the spatial impression of the viewer can be substantially improved, since the viewer can regard the 3D-sketch from different angles just by moving his head, which meets natural habits. This probably helps to understand 3D geometry more quickly. In the actual setup the magnetic tracking system "Flock of birds" is used. Because of interferences between the magnetic fields of the tracking system and the CRT monitor, the position of the displayed objects is a little unstable. For longer work with the system it is better to turn off the head tracking. A non-magnetic tracking system would be more useful in this case.

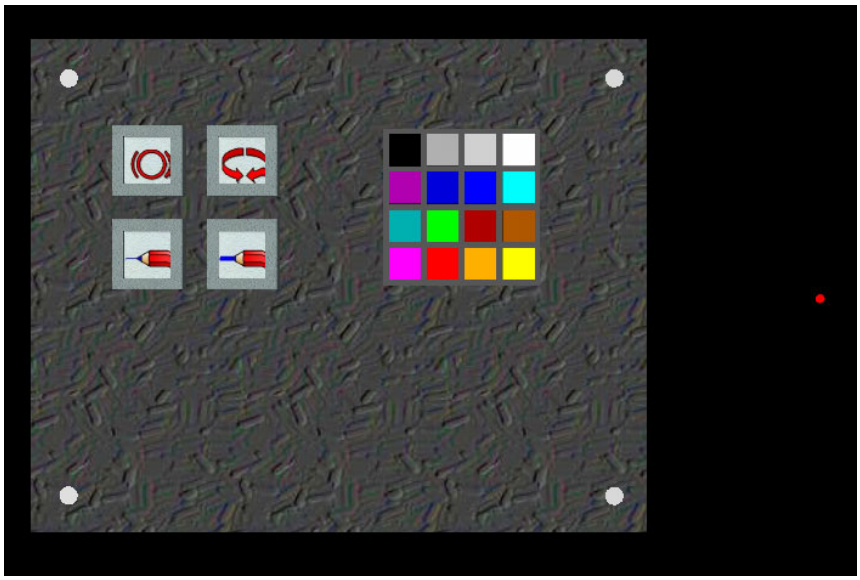

Figure 4: Menu for changing line properties

Actually two student-projects use the 3D-sketching tool in early phases of conceptual design. One of them is designing a stand for the Hanover Industrial Exhibition. An early sketch is shown in Figure 5. The work with the 3D-sketching tool will give valuable hints on how to improve the system. Also the limitations of the actual system can be determined. For example it will not be easy to make sketches of products that consist of many rotational symmetric parts, since it is hard to draw such objects just by the help of lines.

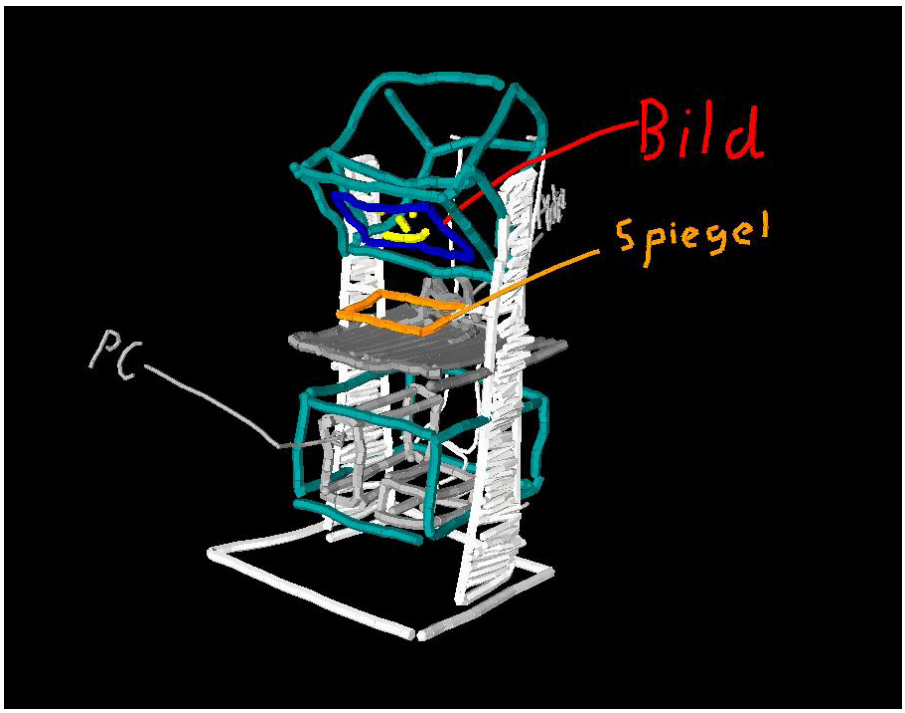

Figure 5: 3D-sketch of a stand for presenting the 3D-sketching tool

Further development of the 3D-sketching tool will be focussed on the realisation of an optimized ergonomic human interface and on the integration of alternative input devices. In this way a tool could be realized, that productively supports intuitive and creative work during the early phases of the design process.

Beyond technological improvement, it is essential for future application of the 3D-sketching tool to be integrated into existing development processes and IT environments. This concerns particularly the linkage to or even integration into existing CAD systems. In the long run it should be possible to concretize objects produced with the 3D-sketching tool in a CAD system and to include already existing parts into the 3D-sketching environment. The process of step-by-step concretizing a vague 3D-sketch to a CAD model could be supported by means of software assistants. In the future the 3D-sketching tool could be an essential feature of next generation CAD systems for making creative solution development possible.

4. Conclusion

A 3D-sketching tool for the early phases of the product development process was developed. By the help of this device, it is possible to represent vague and diffuse product information in 3D. The use of the 3D-sketcher is intuitive and first experiences with the 3D-sketching tool were promising and showed potential for further development.

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