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COMPREHENDING A HAND MOTION LANGUAGE IN SHAPE CONCEPTUALIZATION

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ABSTRACT

This paper reports on a study concerning the comprehension of an experimental hand motion language in shape conceptualization. Hand motion is regarded as a prospective input mechanism for computer aided conceptual design systems for initial shape design of consumer durables. Our hand motion language has been developed based on the analysis of the (a) information necessary to describe shape concepts, (b) descriptive and indicative capabilities of human hands, and (c) cognitive and perceptive aspects of processing hand motions. This language was used in designed experiments to describe simple, compound and hybrid shapes for designers and tested with respect to comprehensibility. The subjects were asked to reconstruct the presented shapes by sketching on paper. Comprehension of the hand motion language has been evaluated in terms of fidelity and efficiency. Fidelity was expressed in terms of the number of deviations of the sketches of the test shapes from the existing CAD models. Efficiency was expressed as the proportion of the time needed to understand the test shapes communicated by hand motions and the time needed for the presentation. The results clearly indicate the potentials of a HML in shape conceptualization. In addition, the experiments revealed several new issues related to the application of the hand motion language in a multi-modal interface. The most important one is the need of chunking of the hand motion sequences in a way that enables the computer system to reliably reconstruct shapes and the designers to understand the formation of shapes on a higher semantic level. These issues will be addressed in our future research.

1. INTRODUCTION

Hand motions and gestures received a lot of attention in research in the last two decades because of the opportunities they offer for human-computer interaction (HCI). Many researchers believe that more natural and effective interfaces can be developed based on these resources for computer-aided design systems. One branch of research targets the *technological platform*, i.e., hardware and software systems for detection, recognition, interpretation and application of hand postures and signs (Pavlovic, V. et al., 1997). Another branch of research deals with *human aspects* such as physiology, cognition, perception, and apprehension of hand motions and gestures. Signs generated by hands have been studied as an individual instrument for communication between designers and design support systems, as well as part of a multi-modal interface. The scope of our research has been narrowed down to *hand motions* by which information for shape conceptualization can be generated by designers and processed by computer systems. The ultimate goal is to use hand motions in three-dimensional conceptualization and design of shapes so intuitively and effectively as it is done with two-dimensional sketching.

Our vision is a *collaborative virtual design environment* (CVDE), in which conceptualization and design of shapes is based on, among other things, a dedicated *hand motion language* (HML). We assume groups of designers working at remote locations and using hand motion in their collaboration (Horváth, I. and Rusák, Z., 2001), or alternatively verbal communication (Dorozhkin, D. V. and Vance, J. M., 2002) and other advanced forms of conventional design and representation means (Lim, S. W. et al., 2001) to externalize shape concepts. They jointly build and manipulate multiple shape variants in the distributed virtual environment, which provides true three-dimensional visualization and enables concurrent manipulation of shared shape models in real-time.

1.1. Human hands in action

Human hand is a biological mechanism, a versatile natural manipulator of the human body. As such, it exerts forces and produces motions that are used in controlled *motor functions*. Featuring polymorphism, human hand has *generic characteristics* based on which it is treated as a *genotype* in research, except when the amplitude of variation and the specific features of an actual *phenotype* are studied. The possible changes of the hand's shape are determined and constrained by its physical articulation.

Although often used as synonyms, the terms hand postures, motions and gestures have different meaning in our terminology. *Hand postures* are understood as individual formations of the hand combined with static movements. Usually classified as one-handed, two-handed and double-handed, *signs* are manifestations of hand postures in various positions. Brought about by the arm, *hand motion* is a change in the spatial position of the hand and means a particular manner of moving the hand. While hand postures involve normal and hyperextension, flexion, palmer and radial abduction, ante- and retroposition, hand motions are combination of hand postures and controlled movements of the hand in space. Motion of the hand enables a variety of activities, but each time obeys certain *kinematical constraints*. Human gesture is typically an action to convey certain indication and evoke a response. *Hand gestures* are combinations of hand postures and dynamic hand movements. They are used to express thoughts and emotions, emphasize speech, and indicate intent and attitude. In general, hand motions carry less semantic content than hand gestures, but they are more powerful in carrying out actions, e.g., externalizing shape concepts.

In our context, hand motions have two major advantages over hand gestures. First, they represent not only a communication tool, but also an important *interaction and manipulation tool* for collaborative work (Dix, A. et al., 2001). Second, they offer better opportunities to realize *virtual presence* in distributed collaborative work environment, than human gestures (Su, S. A. and Furuta, R., 1994). Human motions, including hand motions, are typically processed based on *instrumented detection* (Yu, H. et al., 2000) or *computer vision* (Moeslund, T. B. and Granum, E., 2001). One of the most challenging problems is to extract hand motions from complex views (Triesch, J. and von der Malsburg, Ch., 1996). Instrumented detection can be enabled direct sensors, e.g. data gloves that must be worn by the user and attached to the computer. Alternatively, it can be done by indirect trackers and scanners that leave the hand naked but introduce difficulties in real-time recognition (Dourish, P., 2001).

1.2. Research methodology

Our research focuses on the expression and comprehension of shape related information by hand motions. We take for granted that appropriate devices can extract the information carried by these physical 'utterances' of the hand. Due to the richness in information and the speed of the normal hand motions (5 - 8 m/s), a structured HML is believed to be an effective means for externalization of shapes and for inputting them to computer aided conceptual design systems. The scheme of our research methodology can be seen in Figure 1. An extensive literature study has been done to survey the state of the art of hand motion and gesture recognition, processing, and use in product design applications. Interviews were held with industrial designers to learn their opinion about new creative interfaces for shape design and shape conceptualization systems. Our preliminary studies were oriented, on the one hand, to the physiological, cognitive, semiotic and ergonomic aspects of generating and processing hand motions. On the other hand, natural surface based representation of shapes has been investigated from the viewpoint of a unique and effective modeling technique for shape conceptualization.

For the time being, we do not consider any technological and computational problem of detection and recognition of hand motions, or any computer internal modeling or imaging problem of specification, composition and manipulation of multiple evolving shape concepts in a collaborative environments. The first objective of our research was to systematize and formalize the shape related physical utterances

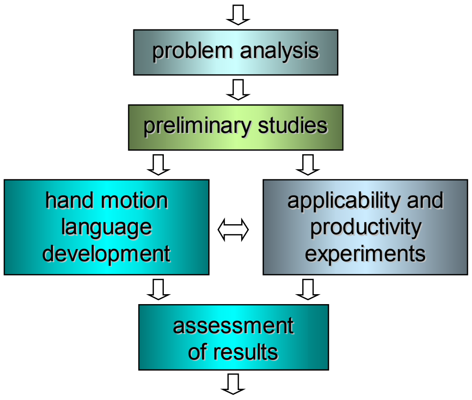


Figure 1 The scheme of research

of the human hand in an experimental HML. The second objective was to study the expressiveness and comprehension of the hand motion language, which have been measured in terms of efficiency and fidelity. Experiments have been designed to obtain feedback from designers taking part in shape conceptualization sessions. To this end, a set of test shapes (simple, compound and hybrid shapes) have been defined and modeled by a commercial CAD system. Simultaneously, we worked out and optimized hand motion sequences (words and sentences) for the experiments, to describe the same shapes for the test persons with the experimental HML. In the experiments the test persons were asked to reproduce the shapes presented by hand motions, according to their best understanding. In order to avoid unwanted influence of computer aided design systems whatsoever, we employed conventional hand sketching as a representation means. Finally, the experiments were systematically evaluated and the comments made by the test persons were analyzed. These all together gave us input for further improvement of the hand motion language for which a specific recognition technology will be developed in the second phase of our research.

1.3. Objectives and structure of the paper

As indicated above, the background research has been decomposed to four parts: (a) aggregating knowledge about the role and nature of hand motions, (b) development of the hand motion language for shape conceptualization, (c) experimenting with the functionality, cognition and comprehension of the HML, and (d) application of hand motion as an input mechanism in a shape conceptualization system. In this paper only the second and third parts will be dealt with. Nevertheless, we describe the assumptions and the process of our research in detail, and summarize the results of the experimental and development work. The goals of Section 1 are to introduce the readers to our specific problem and to clarify our interests and position. Section 2 is a structured survey of the related research with special attention to the three main functions of human hand. Section 3 presents the elements of the hand motion language developed for shape conceptualization. Section 4 deals with the practical experiments and the results obtained from the experiments. Section 5 discusses the results and concludes about the possible improvements of the experimental hand motion language and the future research.

2. ON RELATED RESEARCH

The functions of the human hands have been sorted in manipulative, indicative and descriptive categories. Investigation of the hand in these functions is in the focus of researchers for a long time (Aggarwal, J. K. and Cai, Q., 1999). *Manipulative functions* exploit the motor capabilities, that is the ability of exerting force and adapting the shape in order to grasp objects. *Indicative functions* are for generating signs and gestures with the goal to communicate concepts and actions. *Descriptive functions* simulate an action of description by changing the form and position of the hand. A clear-cut separation of the functions is difficult to make since in general one of the functions is dominant, but it is accompanied by the other two functions. For instance, in the case of handwriting, the manipulative function dominates (grasping the pencil), but it is to enable the descriptive function (formation of lines). Writing can be recognized through its indicative function, in other words, based on the typical posture the hand takes while it writes.

2.1. Research in manipulator functions of hands

Hand motions can be described on the basis of kinematics and kinetics. Kinematical description considers the geometry, position, orientation and deformation. Hand motions have been classified and described as rigid and non-rigid motions. Non-rigid motions are further classified as general and constrained motions (Kambhamettu, C. et al., 1994). General motions are fluid and elastic motions, constrained motions are conformal, homothetic, iso-metric, quasi-rigid and articulated motions. Human hand motion is typically studied as articulated motion (Wu, Y. and Huang, T. S., 1999). Kinetics considers forces, moments and torques in generating movements. Based on visual investigations, (Gavrila, D. M., 1999), the human hand has been modeled as a multi-DoF rigid body system, (Huang, T. S., 1990), and deformable body system (Heap, A. J. and Hogg, D., 1996). To consider the rules, constraint-based modeling, (Lee, J. and Kunii, T. L., 1993), and knowledge-intensive animation of hand grasping, (Rijpkema, H. and Girard, M., (1991), have been proposed. Tracking of the positions and orientations of the hand can be by vision-based and non-vision-based methods such as magnetic, acoustic, and inertial tracking. Another branches of research are concerned with reconstruction of hand motions in virtual (animated), (Moccozet, L., 1996), and physical forms (Badler, N. I. et al., 1991).

2.2. Research in indicative functions of hands

Focusing on semantic aspects, research in hand gestures studies the (a) formation of hand gestures, (b) recognition of hand gestures, (c) interpretation of hand gestures, and (d) conversion of hand gestures to commands of, for instance, shape modeling systems. Hand gestures have been classified as (a) symbolic (hand posture indicating concept or object) or modalizing (following speech), (b) pantomimic (representing interaction), (c) iconic (representing object), (d) deictic (expressing feeling or metaphor), and (e) self-adjuster (emphasizing significance, unimportance, or stimulation) gestures (La Viola, J. J., 1999). Two modes of gestures are delineated: gestures as a sign language, and gestures as a spatial navigation.

A major field of research is sign language recognition. Human sign recognition means understanding intuitive signs (e.g. pointing finger) or professionally used signs (e.g. by signalmen at airports). Interpretation of the latter is easier due to its formalization. Gesture recognition is a wider field than sign recognition. The basis of extracting the meaning of gestures is the visual image of the hands. Recognition can be interactive or automated. Automated recognition of signs and gestures needs two processes: (a) observation process based on sensors, and (b) feature classification for extracting gestures (Holden, E.-J. and Owens, R., 2001). Typical techniques are pattern matching (Tamura, S. and Kawasaki, S., 1988), feature extraction (Imagawa, K. et al., 2000), model matching (Shimada, N. et al., 1995), and interactive learning (Lee, Ch. and Xu, Y. S., 1996). Tobely, T. E. et al. (2000) applied a randomized self-organizing map algorithm for dynamic recognition of hand gestures with normal video rates. Hidden Markov functions have also been applied to recognize hand gestures (Nam, Y. and Wohn, K., 1996). Up to now, the nature of hand gestures and their roles in various applications, e.g., in communication of handicapped, navigation in public areas, (Watson, R., 1993), but also in description of shapes, (Hummels, C., 2000), have received more attention than dedicated hand motions.

2.3. Research in descriptor functions of hands

Descriptor functions are related to the use of hands to point at objects, indicate a point in space, designate a domain in space, emulate an analogy of something, or sweep following a trajectory. Researchers have been studying the nature and features of these hand motions, for instance, in two- and three-dimensional sketching. The characteristic motions are sensed, identified and the content describing shape- and shape-related information is extracted. For detection and recognition of hand motions both real-time and posterior technologies are implemented and tested. Real-time hand motion recognition technologies involve a motion sensing process where the features of a motion are extracted from the input data. Both the principle of active signaling (e.g., data gloves) and direct detection (e.g., laser scanning), (Ahmad. S., 1995), have been used to obtain information from the hand motion. Posterior technologies have been developed based on passive data extraction technologies such as image processing. Two-camera systems represent the conventional technology (Abe, K. et al., 2000). Researchers have tried to take the advantage of having specific features in applications, and proposed dedicated solutions such as silhouettes-oriented multi-view tracking (Delamarre, Q. and Faugeras, O., 1999), visual tracking with occlusion handling (Lathuiliere, F. and Herve, J. Y., 2000), and processing in a contextual relaxation scheme (Chen, Y.-Q. and Huang, T. S., 2000).

2.4. Research issues concerning the use of hand motions in shape conceptualization

The preceding subsections not only give an insight in the current state of the art, but also indicated a trend, which is a much stronger interest in the invention of new technologies for detecting and processing hand motions, than in the cognitive, semiotic and human aspects. Our view is in order to facilitate the effective utilization of the technologies, more efforts have to be devoted to human- and design-related issues. As far as the latter is concerned, there are several issues that are not at all or only partially studied until now. That is the reason why we put the development of a hand motion language for shape conceptualization in the center of our research, and decided to investigate its compliance to the designers' expectations and to the tasks of conceptualization.

We have found that this research domain brings in a wealth of research questions. In order to focus our research, we gave preference to the topic of how can designers externalize shapes with the help of hand motions. Obviously, this setting of the focus still implies a large number of research questions, each requesting a dedicated research. Therefore, we further focussed our attention onto two fundamental research questions: Can a comprehensive HML be systematically defined and adjusted to the expectations of practical designers? Can we achieve similar productivity with a HML as with hand sketching?

3. DEVELOPMENT OF A HAND MOTION LANGUAGE FOR CONCEPTUAL DESIGN OF SHAPES

3.1. Preconditions for shape conceptualization

Conceptualization is a blend of (a) generating and recalling a set of associated mental images (concepts), (b) creating contextual associations between heuristic and learnt concepts, (c) externalization of human mental images as observable representations, and (d) creative composition driven by human intuitions, conjunctures, experiences and reasoning. Therefore, use of hand motions in shape conceptualization is preconditioned as follows:

(a) Since shapes and elements of shapes are spatial concepts, a proper representation supposed to be generated in the 3D Euclidean space. Representation in lower dimensions introduces abstraction and extra thinking processes.

(b) The mode of shape conceptualization has to support the least cognitive commitment of designers. The more the designer think about the interface he uses, the more he hindered in creativity.

(c) Unique 3D model has to be generated; otherwise designers will manipulate the representations, rather than the real model of the shape. As a unique representation, natural surface representation has many advantages.

(d) The shape model has to allow incompleteness, vagueness, impreciseness and under-definition. The designer should not be forced to think about the completeness of model generation.

(e) The generated shape entities and any manipulation of the shape model have to be immediately visualized.

(f) Shapes of arbitrary morphological properties, sizes and complexity have to be conceptualized with the minimum mental effort and in real time.

(g) The hand motions used to express shape concepts have to be easy-to-produce for the designers, and easy-to-process for the modeling systems.

(h) Since shape conceptualization often takes place in collaborative virtual design environments, a hand motion based shape modeling language has to support model sharing and collaboration.

Several attempts have been made to computerize hand sketching as well as to develop other form giving techniques. Among these, three-dimensional sketching and virtual claying are the closest to the expectations of stylist and designers.

3.2. Considering cognitive aspects

Hand motion is believed to be an effective and fast means in the process of converting ideas to models. Showed in Figure 2, the cognitive model of conceptualization explains that communication means that are about the same speed of human thinking and ideation seems to be the most natural for designers. The key issue related to any practical technique for shape conceptualization is the time that is needed to get from ideation to model creation. The average speed in the internal loop of activities comprising ideation, presentation and reasoning is 10^{-1} to 10^{0} s, and in the external loop involving presentation, reasoning and model building is 10^{1} to 10^{0} s. The techniques that lag behind these values hold back creativity. The reason why hand sketching became a standard presentation technique for shape conceptualization is that the time needed for a sketch-based presentation and modeling is in harmony with the duration of ideation and reasoning actions as well as with the cognitive mechanisms of conceptualization.

From a cognitive point of view, shapes can be paradigmatic (determined by physical laws), or syntagmatic (implied by aesthetic impressions). Shapes can be monolithic or composite, and are usually described as of rigid bodies, i.e., no change of shape of any form is considered. A shape concept may express a generic reflection of a category of shapes, a mental impression or image of a concrete shape, an analogy of an observed shape, or an abstract or generalized idea of a class of shapes. Shape conceptualization is known to be an intuitive, rather than a structured process.

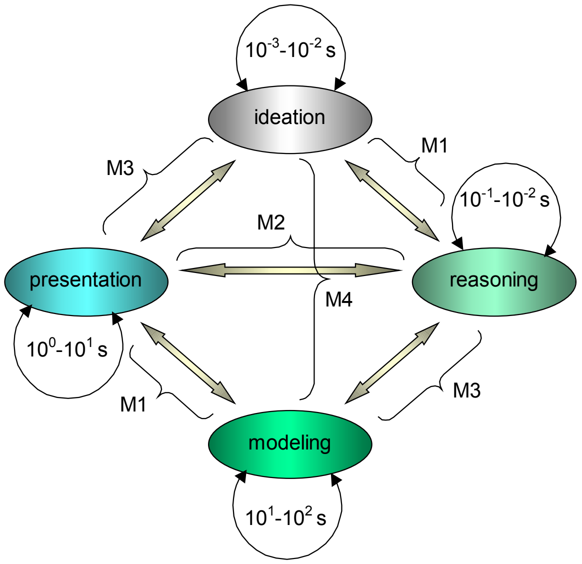


Figure 2 Cognitive scheme of conceptualization

A shape evolves in the course of shape conceptualization and design to fulfill the criteria or to satisfy the constraints. The evolution can be observed in the advancement of the extent of detailing the shape. In the industrial design practice, generic, global, local, and specific shapes are usually identified as typical classes of detailing, even if there is no sharp demarcation line between these subsequent classes. Generic shape is actually the first tentative idea of a shape, which carries information only about the morphological genus of the shape. Global shape describes the morphological character by indicating the form of the components and the macro-geometry level arrangement of a shape. Local shape describes the local features of a shape taking into account the global shape too. Specific shape extends the model with further geometric refinements in terms of both the global shape and the local shapes. These kinds of shapes reflect the general shape design process, which typically goes through the phases of shape conceptualization, shape embodiment, shape detailing, and shape refinement.

3.3. Semiotics and formal definition of hand motion language

A formal modeling language comprises three types of constituents that have to be formally specified: (a) the set of correct symbols, (b) the rules of concatenating the symbols into words, and (c) the grammar for composing sentences from the words. As a formal language, HML is based on the postures and movements of human hand. It has been developed using the analogy of a verbal-textual language, which consists of an alphabet and a grammar that interweave in the language. Words and sentences are created from the letters of the alphabet according to the grammatical rules to be applied. From the sentences paragraphs and chapters are constructed according to the context of communication.

Called terminal symbols in the theory of formal languages, the letters of the HML are signs produced as postures of the hand. A purposeful combination of sequences of changing postures of the hand or the hands is a word of the HML. Thus, words represent the lowest semantic level of constructive actions of shape conceptualization. As in the spoken or written language, a sentence is composed of words that are needed to express the intended semantics. A sentence of the HML is a sequence of words (i.e., hand motions) that is needed to generate the components of a simple shape or to manipulate it. The words are selected as the semantics and the grammatical rules imply it. A paragraph is a sequence of sentences that are needed to describe a simple shape. Finally, a chapter is a set is to construct one-piece compound and hybrid shapes, or multi-piece shape assemblies.

Let the letters, words, sentences, paragraphs and chapters of the HML be denoted by l, w, s, p, and c, respectively, and the sets of them by the same capitalized letters. Let the grammatical rules for words be denoted by q and for sentences by r. Let Σ denote the predefined set of unique hand motions Σ_i. Thus, l is a set of hand motions such that

$$l_k = \Sigma_i \mid \Sigma_i \in \{ \Sigma_o, \Sigma_1, \ldots, \Sigma_j, \ldots, \Sigma_n \} = \Sigma \qquad (1)$$

where: Σ_i is a unique hand motion, and $n \neq 0$. A word of the HML is a construct as follows:

$$w = (l_k, q_j) \qquad (2)$$

where: $k = 0, \ldots, m$, $m \neq \infty$, and $j = 0, \ldots, n$, $n \neq \infty$. According to its meaning, a hand motion can be either procedural, Σ_i^p, or constructive, Σ_i^c. A word consisting of (letters of) procedural hand motions is a procedural word, w_i^p, and those of constructive hand motions are constructive words, w_i^c. A *procedural word* provides information for the process of shape conceptualization, while the *constructive words* provide information for the shape model. Hence, the total set of words consists of the subsets of procedural and constructive words:

$$W = \{ w_i \mid w_i \in (W^p, W^c)\}. \qquad (3)$$

Typical procedural words are the words ‘start’, ‘stop’, ‘share, and ‘obtain’. The main reason of defining procedural words is that computer controlled detection, scanning and conversion of hand motions require well recognizable starting and end postures that enclose the constructive hand motions. The complete set of w_i^p is given in Figure 3. The constructive words can be grouped according to the semantics of the information they convey to the shape model. Based on the information contents they can be geometric, w_i^{cg}, (Figure 4), identification, w_i^{ci}, (Figure 5), connectivity, w_i^{cc}, (Figure 6), positioning, w_i^{cp}, (Figure 7), scaling, w_i^{cs}, (Figure 8), and assembling, w_i^{ca}, (Figure 9), words.

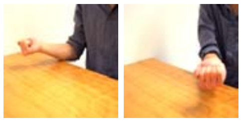
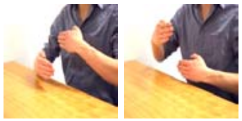
Words	Descriptions	Signs
Neutral	Designer is inactive	
Start End	Opens a sentence Closes a sentence	
Stop Resume	Discontinues a sentence Restarts an unfinished sentence	
Share Obtain	Stops to let another designer work on a shape Takes over a shape to further work on it	
Undo Redo	Cancels an unwanted or faulty sentence Starts again a previously undone sentence	

Figure 3 Procedural words

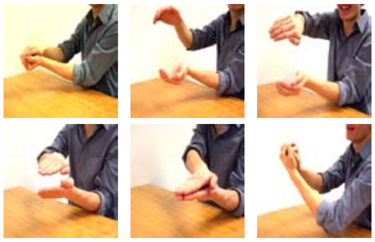
Words	Descriptions	Signs
Plane	Specifies a planar surface as halfspace	
Cylinder	Specifies a cylindrical surface as halfspace	
Cone	Specifies a conical surface as halfspace	
Sphere	Specifies a spherical surface as halfspace	
Ellipsoid	Specifies a ellipsoidal surface as halfspace	
Free form	Specifies arbitrary free form surface as halfspace	

Figure 4 Geometric words

A sentence, s, of the HML is a composition of words obeying to the rules of the language:

$$s = (w_i^p, w_j^c, r) \qquad (4)$$

where: $i = 0, \ldots, m$, $m \neq \infty$, and $j = 0, \ldots, n$, $n \neq \infty$. Less formally, a sentence is a shape formation oriented arrangement of procedural and constructive words. A paragraph is a composition of sentences, i.e.,

$$p = (\cup s_i) \qquad (5)$$

where: $i = 0, \ldots, m$, $m \neq \infty$. Finally a chapter, c, is a composition so as:

$$c = (\cup p_i) \qquad (6)$$

where: $i = 0, \ldots, m$, $m \neq \infty$.

One of the major objectives in defining the HML was to

Words	Descriptions	Signs
Identify point	Indicates and selects a point of a shape	
Identify curve	Indicates and selects a curve or line of a shape	
Identify surface	Indicates and selects a surface or plane of a shape	
Identify object	Indicates and selects a shape	

Figure 5 Identification words

minimize its dependence on temporal, morphological and spatial variances.

Likewise in conventional computer aided drawing and geometric modeling, macro-level operations offer speed advantage over elementary operations. The situation is the same with hand motions. Combinations of simple words make the shape modeling process not only more effective, but also more expressive. An initial set of compound geometric words has already been defined for testing purposes, but further research seems to be necessary in this direction.

The variety of the compound words that can be produced with two-hands and double-hands has been found extreme large.

Words	Descriptions	Signs
Surface to surface	Specifies face-to-face connection of two surfaces	
Surface to curve, or vice versa	Specifies face-to-edge or edge to face connection of two surfaces	
Surface to point, or vice versa	Specifies face-to-vertex or vertex to face connection of two surfaces	
Curve to curve	Specifies edge-to-edge connection of two surfaces	
Curve to point, or vice versa	Specifies edge-to-vertex or vertex to edge connection of two surfaces	
Point to point	Specifies vertex-to-vertex connection of two surfaces	

Figure 6 Connectivity words

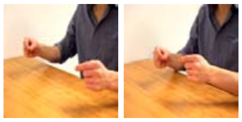
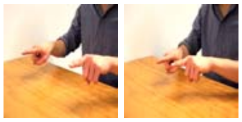
Words	Descriptions	Signs
Turn	Turns a shape around by 90 degrees	
Distance by points	Increases or decreases the distance between points of two shapes	
Distance by curves	Increases or decreases the distance between curves of two shapes	
Distance by surfaces	Increases or decreases the distance between surfaces of two shapes	

Figure 7 Positioning words

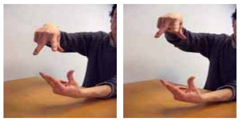
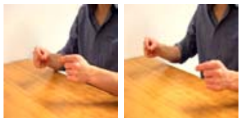
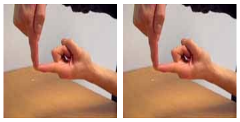
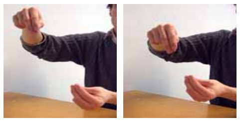
Words	Descriptions	Signs
Size by surfaces	Increases or decreases the distance between two general surfaces or two parallel planes	
Size by curves	Increases or decreases the distance between two general curves or two parallel lines	
Size by points	Increases or decreases the distance between two points	
Angle by surfaces	Increases or decreases the angle between two surfaces	
Angle by edges	Increases or decreases the angle between two lines (tangent or common)	
Zoom in/out	Increases or decreases the shape proportionally	

Figure 8 Scaling words

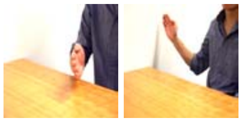
Construct	Puts together entities to form a simple shape	
Deconstruct	Separates simple shapes to shape entities	
Compose	Composes compound or hybrid shapes	
Decompose	Decomposes shapes to elementary shapes	
Assemble	Assembles shapes to form object with DoF	
Disassemble	Disassembles shapes of an object with DoF	
Put aside	Preserves a shape model for later reuse	
Bring in	Retrieves a preserved shape model	
Cut through	Slices a shape model into two parts	
Cut out	Removes part of shape model	

Figure 9 Assembling words

For these reasons, but also for the space limitation, the compound words defined as macros of simple words cannot be discussed in this paper. It must be also noted that the current version of HML does not contain words for deformative shape manipulation or for Boolean- or Minkowski-type compositions.

3.4. Modeling aspects of conceptualization of shapes

In this subsection we elaborate on the modeling aspects of hand motion-based conceptualization of shapes, in particular, on creation and arrangement of the components of simple shapes, and on building shapes of higher complexity. First we discuss some physiological factors that have been taken into consideration at defining the presented set of hand motions. As a bottom line, the anatomical structure of human hands determines what kinds of postures and motions are easy and comfortable to make. Postures requiring hypertension of any of the fingers are not suitable since they put extra strain on the joints and tendons; hence result in discomfort for designers. For instance, flat and convex shapes can be formed naturally by the flexion of the fingers, but the mechanical limits can be reached soon with hypertension that would be needed for concave shapes. Consequently, description of concave shapes is very much limited by the possible extent of hypertension of the fingers.

As a solution, concave surfaces are described as a Descartian composition of a shape profile motion (generatrix) and a trajectory profile motion (directrix). In the case of convex shape the generatrix is the flexion of the hand. This approach allows us to manage with toroidical and hyperbolical shapes. Two-hand and dual-hand motions have also been considered in order to avoid the need for extreme opposite turnings of the hand (Lee, J. and Kunii, T. L., 1995). With these measures hand motions will be intuitive and comfortable for the designers, and do not put any excessive strain on the hands. As an example, Figure 10 shows the sentence of generating a straight cylinder in vertical position that consists of two words, one to describe the vertical cylindrical surface and one to describe the two parallel planar surfaces.

Figure 10 A sentence defining a cylinder

In case of physical objects, the boundary represents the shape for the visual and tactile senses. From a modeling point of view, the boundary of a physical object is a composition of natural surfaces that uniquely and completely represent it. For the hand motion language, geometric words have been defined to describe the natural surfaces, and in combination with the other construction words, to specify the boundary of shapes. Since our application is conceptual design, visualization of the shapes is supposed to happen in a virtual space; therefore, incomplete boundary descriptions can also be accepted. In other words, specification of a conceptual shape can be either complete or incomplete according to the intent and need of the designers. It is an important aspect in shape conceptualization, since the designers might not wish to specify all surfaces building up the boundary of the shape, or do not have enough information to define each natural surface. Basically, the geometric hand motions refer to a half space, a region of which corresponds to a natural surface. The half space is a fundamental concept for the hand motion-based shape conceptualization, since any object can be described by an appropriate combination of finite number of intersecting half spaces. Moreover, the concept of half space naturally offers a separation of the inside and outside of shapes. The range of geometric hand motions designates the region of the half space to be taken into consideration and express its characteristic curvatures.

From a morphological point of view, a simple shape is a common composition of surfaces having no regions of higher significance than the shape itself. As a component, a simple shape is a global one if its dimensions correspond to the extent of the conceptualized shape. A compound shape is a composition of several global shapes. A global shape can be combined with and modified by local shapes. Other manipulation of shapes means changing their shape, sizes, and position. As a component, a local shape has smaller dimensions than the global shape carrying it. Hybrid shapes are arbitrary compositions of multiple global shapes and local shapes. Each kind of shapes is represented as the union of its natural surfaces. The pieces of information needed for the reconstruction of concrete surfaces (such as the type of the surface, spatial position of the surface, the extent of the surface, the material side of surface) are obtained directly from the hand motions. The half spaces generated by the hand motions are interpreted as infinite boundary surfaces. The intersections of these surfaces are computed and the result is an evaluated shape model.

If we compare this approach to the conventional methods of boundary modeling, then the obvious difference will be the large amount of explicit information, which accompanies each step of shape modeling. But this is exactly how it happens in the real life whenever intuitive representation techniques such as hand sketching are applied. The implicit handling of information, on the one hand, speeds up the modeling process and reduces the efforts needed for modeling. On the other hand, it requires greater mental involvement and results in a level of uncertainty.

4. EXPERIMENTS WITH HAND MOTION LANGUAGE

4.1. Carrying out experiments

The experiments have been done with the involvement of ten subjects. Two of them were practicing product designers (form giving experts), two hand drawing instructors, two developers and programmers of a computer aided conceptual design system, two industrial design engineering students, and two human-computer interface experts. Six shapes, representing increasing morphological and procedural complexities, were chosen for the experiments (Figure 11). The same researcher was the presenter in each experiment, in order to reduce the influence of having different presenter. She was proficient in the use of the experimental hand motion language. Each experiment consisted of two sessions. In the first session the logic and the set of sign of HML were not explained to the test persons. The only information they received was about the task and the way of conducting the experimental sessions, but there was no clarification at all on the signs and the whole of the hand motion language. Before the presentations they were asked to pay attention to and understand the presenter as much as it was possible. They could stop the presenter whenever and as many times as they wanted, they were allowed to ask her to repeat the last sentence or sentences, however, they were not supposed to ask explanation about the meaning of what was currently presented and the relationship to the formerly presented sentences. The presenter described the same six test shapes by hand motions, and the test persons were to reconstruct them by conventional hand sketching in the form of line sketches. Note that in this case the hand sketches substituted the visual presentation of the results by computer. The reason was to avoid the influences of computer technology; in particular, the associations to certain commands typically used in computer aided geometric modeling. The subjects could sketch on the coded paper sheets whatever they thought the hand motions were about.

Before the second session started, the subjects received detailed explanation on the categories of the words and signs of the hand motion language (geometric, connectivity, positional, scaling and composition words), and about the units of communication (the hand motion sentences). They could ask for further clarification about the signs, the logic of presentation, the particular use of signs, but not about the test shapes. Then the same exercise was repeated according to the scenario discussed above. During the presentation, however, they had no opportunity to ask questions from the presenter or to discuss the problems with the interpretation of what was presented.

The experiments were held in a typical media room. Both the presenter and the subjects were recorded on videotapes. The time elapsed by the session, the nominal sketching time and the time needed for the presentation of the HML sentences were all measured. In addition to the time measurements, the behavior of the subjects and qualitative aspects of the presentation were also observed. The results were digitally archived, and both quantitative and qualitative evaluations were made.

4.2. Evaluation of results

The main objective of the evaluation of the experimental results was to attain information about the comprehension of the hand motion language in practical application. Therefore, the data recorded in textual, numeric and/or visual forms have been evaluated according to two aspects: (a) fidelity of the representation of the shape information communicated by the HML, and (b) efficiency in terms of the time needed to reconstruct the shapes by hand sketching. These values have been determined for each subject and for each test shapes. Below, we briefly explain the procedures we followed.

Fidelity has been expressed in terms of the existence of shape features and their arrangement in the proper context. The form features of each test shape have been identified and the shapes have been converted to a form feature model. An example is shown in Figure

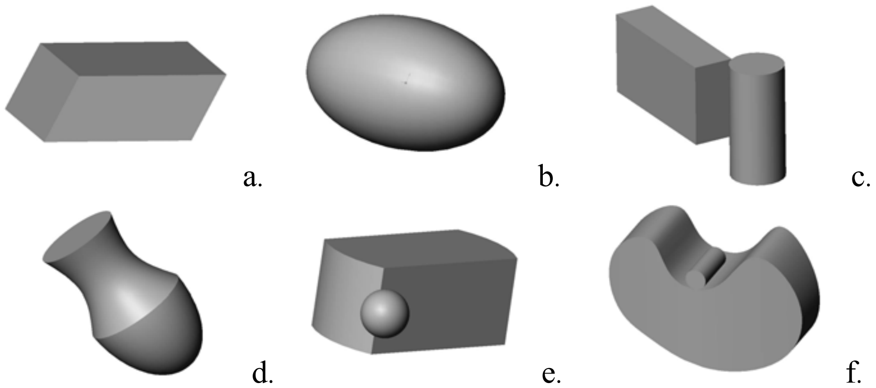
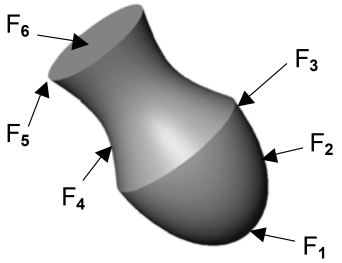


Figure 11 The test shapes



F_1	elliptical point
F_2	convex elliptical surface
F_3	convex-concave sharp edge
F_4	concave elliptical surface
F_5	concave-flat sharp edge
F_6	flat surface

Figure 12 Form features of test shape #4

12. We were interested in if (a) the feature could be find in the hand-sketched representation of the shapes, and (b) they were represented in the proper contexts. The former means that the feature was completely represented and could be identified unambiguously in the sketch. The latter means that the feature was shown in the right place and orientation, and it was correctly connected to other features. Accordingly, + +, + –, 0,– +, – – values were given. For instance, if the geometry of a feature was unmistakably represented and its size, position and orientation as well as the interfacing with the base shape were correct than it received + +. If a given feature existed in the sketch but it was not in the right context, or a different feature was found in a given context, then + – and – + was given, respectively. The value 0 means that we could not evaluate something for existence, or context. For a more transparent representation in bar diagrams, the summed up values were converted to relative percentages per test shapes and test persons. Fidelity was expressed as the number of deviations of the sketches of the test shapes from the existing CAD models. We calculated the fidelity index of a sketch by summing up and averaging the values received for existence and context.

In the case of efficiency, we were interested in the actual time needed for the interpretation of the HML. To calculate the interpretation time (t_i), the total time of reconstruction of a shape (t_t), the nominal time requested to present the shapes by the HML (t_{HML}), and the nominal time that was actually used for sketching (t_s) were measured. Then the time needed for the interpretation of the hand motions was calculated as:

$$t_i = t_t - t_{HML} - t_s \qquad (7)$$

The values have been calculated per shapes and persons. Efficiency was expressed as the proportion of the time needed to understand the test shapes communicated by hand motions and the time needed for the presentation.

4.3. Evaluation of the efficiency data

The results of the efficiency evaluation are presented for each test shape in Figures 13 to 18. The category axis shows the test persons in the first session and in the second session. On the value axis the time elapsed is indicated in seconds. In order to be able to visually compare the time requests of the different test shapes, the same time scale was applied to the value axis in each diagram. The height of the columns is the total time of reconstruction (t_t) needed by a test person for a given test shape. Each column has been split to show the pure time required for the interpretation of the hand motions (t_i), and the time needed to sketch what was understood (t_s). Since it does not add extra information to the statistics, the standard time of presentation of the hand motions (t_{HML}) does not appear in the diagrams. Index 'a' indicates the results in the first session and 'b' the results in the second session in which the test persons were already explained on the HML.

In more than 90 percent of the cases, the test persons achieved much better results in understanding the sentences of the HML in the second session. Both the efficiency data and the fidelity data reflect it. While the time sketching elapsed (t_s) remained practically the same, time t_i decreased by 50 percent in average. It shows two things. First, the HML is rather intuitive; people who were absolutely unfamiliar with these signs could interpret them fast, and captured the meaning of the words and sentences with minimal mental effort. It is because the hand motions and the meaning of them are based on the postures and motions that are commonly used in our everyday life to express shape related concepts. Second, understanding the specific meaning of, for instance, the procedural, connectivity, positioning and assembling words significantly contributed to the decrease of the time needed to construct the compound and hybrid test shapes. Having better understanding of the shape presented by HML, the test persons not only performed better, but also produced better results from a fidelity point of view.

Further analysis of the experimental data explored other facts related to efficiency. We found that the interpretation time for the completely inexperienced test persons were in average much less than the time needed by our researcher, experienced CAD user, to model the shapes in a CAD system. On the other hand, the time that was needed for the presentation of the test shapes by means of the HML were also much less than the CAD modeling time for the respective shapes. According to us, these are important findings since HML will be used in a quick and dirty conceptualization of shapes. The dependence of the efficiency data on the test persons was not found to be characteristic.

4.4. Evaluation of the fidelity data

The other aspect of the evaluation of the data was the correctness of interpreting and sketching the test shapes described by sentences of the HML language. It has been expressed in terms of the fidelity, which has been introduced as the measure of deviation of the features of the test shapes in the sketches from the features recognizable on the CAD models. The results of evaluation of fidelity are presented, again per test

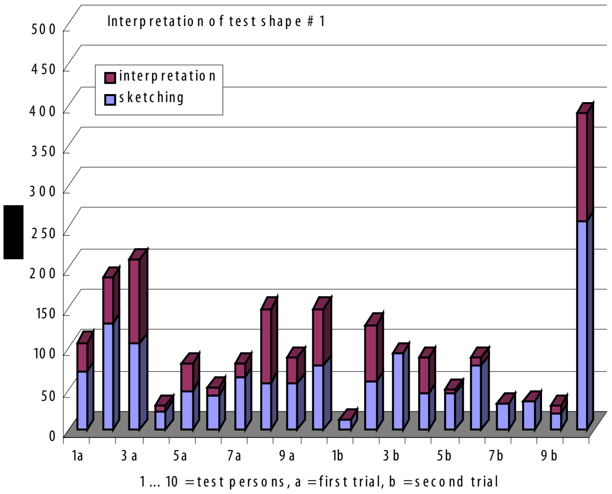


Figure 13 **Efficiency data - test shape #1**

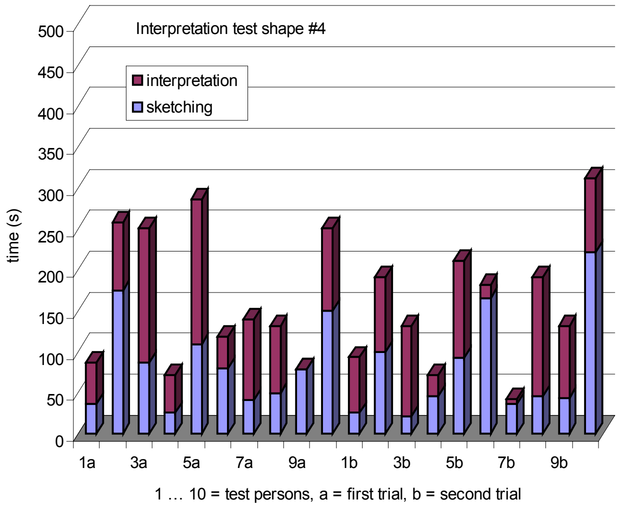


Figure 16 **Efficiency data - test shape #4**

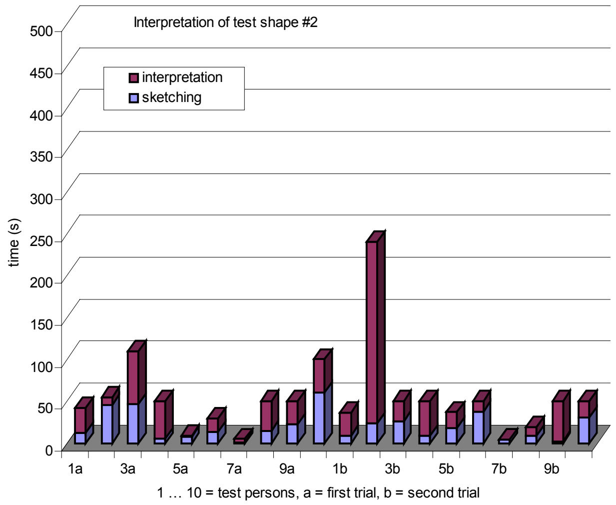


Figure 14 **Efficiency data - test shape #2**

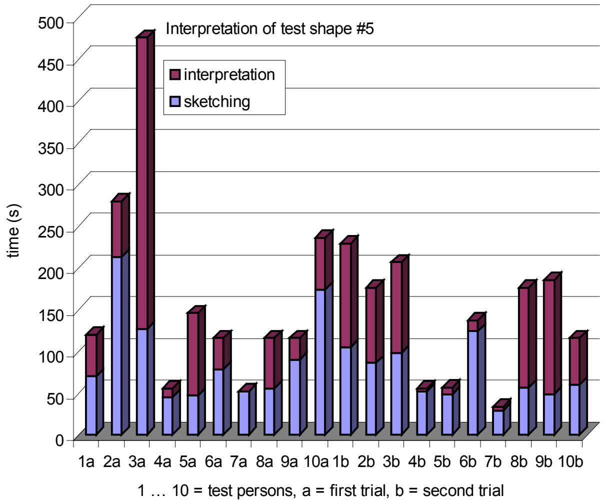


Figure 17 **Efficiency data - test shape #5**

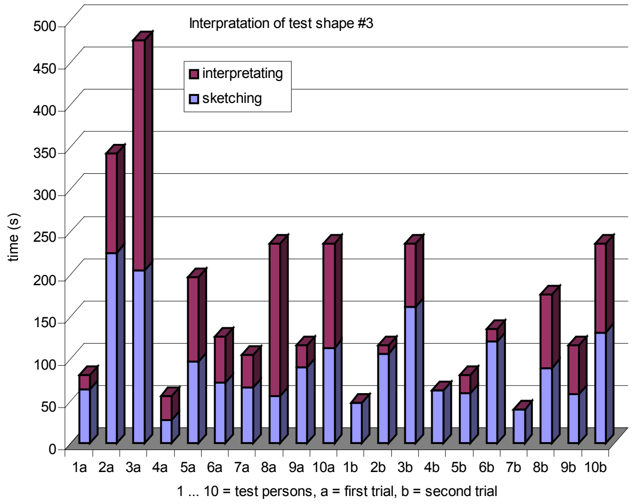


Figure 15 **Efficiency data - test shape #3**

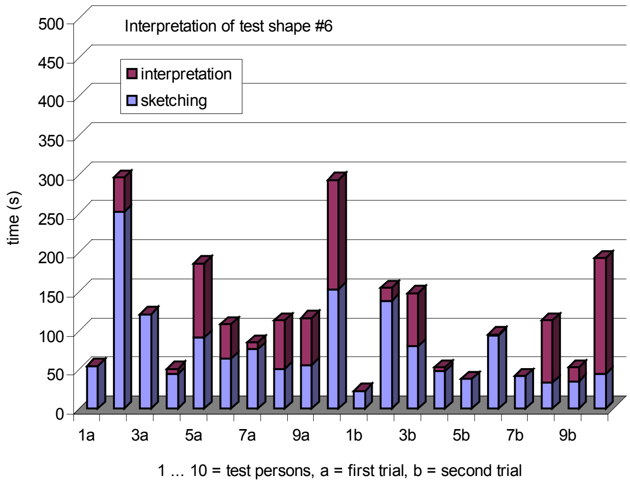


Figure 18 **Efficiency data - test shape #6**

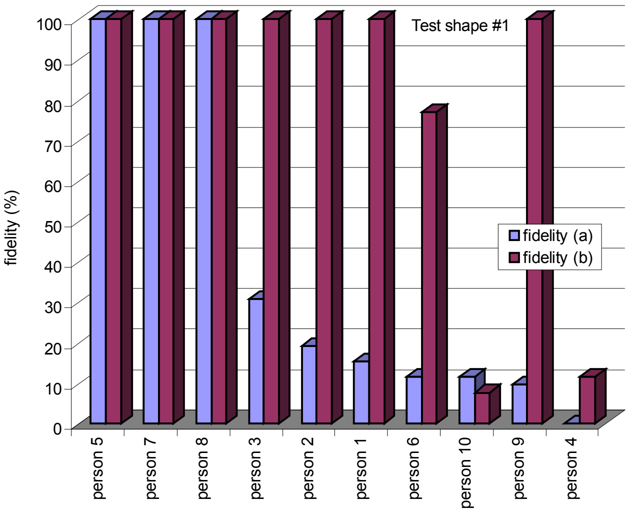


Figure 19 Fidelity data - test shape #1

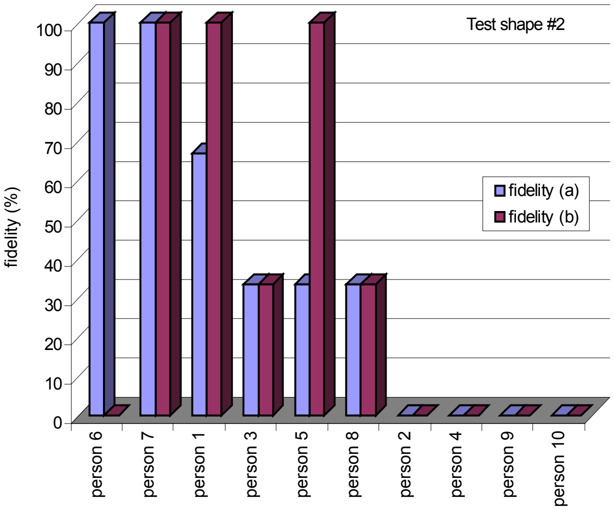


Figure 20 Fidelity data - test shape #2

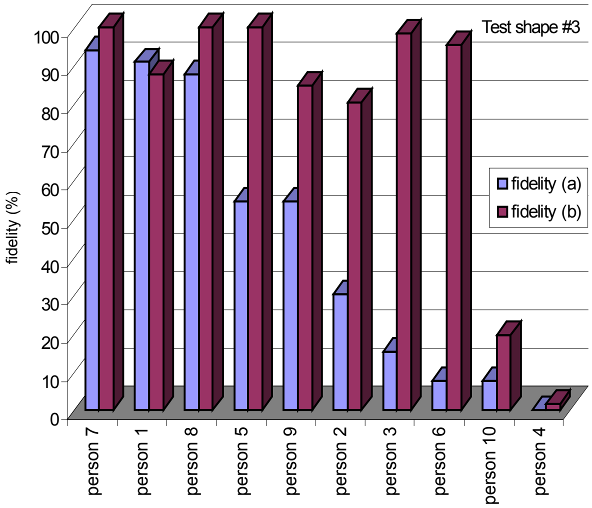


Figure 24 Fidelity data - test shape #3

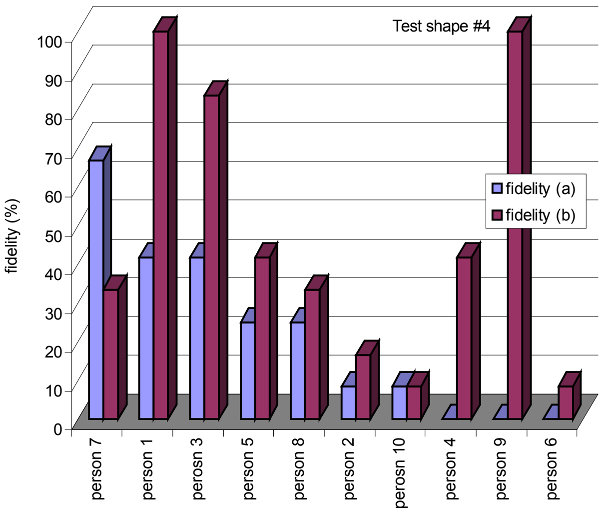


Figure 22 Fidelity data - test shape #4

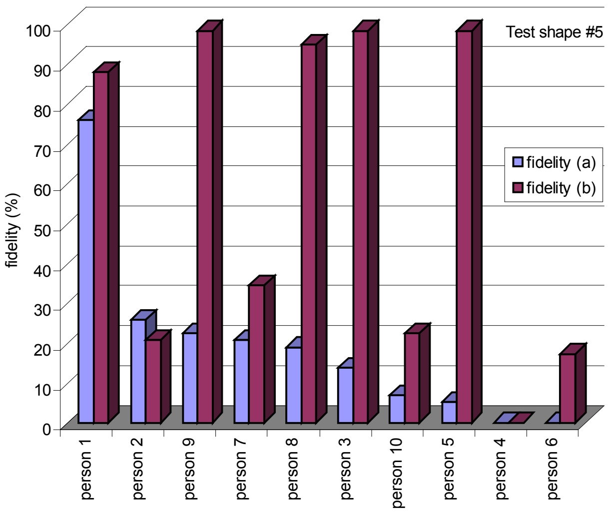


Figure 23 Fidelity data - test shape #5

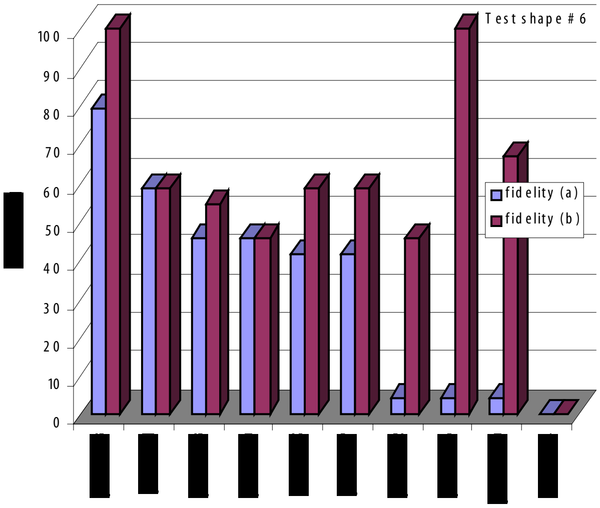


Figure 25 Fidelity data - test shape #6

shapes, in Figures 19 to 25. Evaluation of fidelity happened by the method introduced in Subsection 4.2. In each Figure, the category axis shows the test persons. For presentation the measured data, dual-bar diagrams have been constructed, with the left bars showing the fidelity in the first sessions, and the right bars showing the fidelity in the second sessions. On the value axis the fidelity is indicated in percentages that express the proportion of the correctly represented shape features of the hand sketches and the features identified on the CAD model of the test shapes. The diagrams show the values in a descending order based on the first sessions.

Two characteristics of the distributions can be observed directly. For all test shapes, the average fidelity values varied in the range from 17 percent (test shape # 5) to 41 percent (test shape #3). While test shapes #2 and # 4 were a kind of tricky for many test persons, test shapes #3, #5 and #6 proved to be challenging too since they were compound shapes (containing components of the same size) and hybrid shapes (consisting of components of sizes of at least one magnitude difference). Considering the fact that the test persons did not know anything about the HML before the first session, these values seem to be acceptable. Figures 19 – 25 also show the strong dependence of the achieved fidelity on the experiences and skills of the test persons. In the light of these finding, it seems to be obvious that further experiments have to be designed for a deeper understanding of the personal aspects of efficiency in use.

The other important observation that the explanations provided for the test persons between the first and the second sessions dramatically increased the correctness of the representations. It is evidently shown by the high fidelity values that have been achieved by many test persons with most of the test shapes. Understanding and reconstruction of features of shapes with planar surfaces apparently were easier that that of the features of single- and double-curved shapes.

The largest increase of fidelity can be observed in terms of shapes #1, #3 and #5. Further analysis of the sketches has shown that in the case of test shape #1, it came from the understanding of the macro-based generation of the parallel planar surfaces and of the connectivity signs. For test shapes #3 and #5, the better understanding of the identification, positioning and assembling signs proved to be the most evident reason of improvement.

5. DISCUSSION AND CONCLUSIONS

A class of collaborative design systems seeks to provide multi-modal input possibilities for the collaborating design participants to enable them to hold virtual shape conceptualization sessions. Hand motion is known to be an effective means of human communications, but its application in control and input of real and virtual design environment is still very limited. Element of multi-modal input systems, hand gestures have been found beneficial in simple applications. Our assumption is that hand motions can conveniently be used to specify shapes in particular in conceptual design. It can open up a new direction in shape generation, representation and manipulation that involves vagueness and incompleteness Before going into the development of hardware and software components for the multi-modal interface for a shape conceptualization system, whose modeling kernel already available in the form of a testable prototype, (Rusák, Z., 2003), we wanted to experience with the various media integrated in the interface. In our previous papers we described the efforts and results related to 3D scanning based input and processing of shapes (Spanjaard, S. and Vergeest, J. S. M., 2001) and to verbal communication and control in shape conceptualization (Kuczogi, G., 2001). In this paper we present the concept and implementation of the hand motion language and the first results with its application and testing.

The hand motion language formalizes a set of hand motions that are needed to describe shapes as the ideas about the total shape and its elements emerge in the head of a designer. In order to be able to externalize these ideas the designer has to decompose them to low-level entities and actions (primitives). The preceding two subsections summarized the statistical evaluation of the experiments and explained the numerical results. Based on these findings we can claim that (a) the developed hand motion language appeared as a very spontaneous and organic means for the test persons, who represented a typical sample of potential users in practice, and (b) when the skills of using the HML are obtained, it can be employed in shape conceptualization with good results. The rapidly developing hand motion tracking, scanning and recognition technologies make it possible to process the HML as one component of a multi-modal user interface of a conceptual shape design system. For this reason, we focused on the design and productivity aspects, rather than on technological issues and implementations.

During the experiments not only the understanding and reconstruction performance of the test persons were studied, but also their thinking, perception and behavior. For the reason that the HML assumes a systematic and logical way of reasoning, interpreting the HML presentations was more challenging for the test persons with a dominant visual thinking, as they explained. They were waiting to see the shape in whole based on the sequences of signs, but, in the end, the amount of details was too much and the limitations in memorizing the complex hand motion sequences hindered them to successfully reconstruct the test shape. They perform better with simple shapes than with compound or hybrid shapes. Interestingly, a group of test persons always sketched more than the hand motions implied; they completed the presentations with their assumptions and committed faults this way. The test persons who were incrementally sketching when the hand motions were presented had to make several modifications and adaptations. Even though they spent more time on sketching, the end results were typically better. It brought the issue of proper chunking of the hand motion sentences into our mind – and this will be studied in the follow up phase of our research.

Those test persons, who have intensively used CAD systems in mechanical modeling or, alternatively, took part in the development of CAD software, also caused surprise. They tried to understand and reconstruct the HML sentences according to their background knowledge. For them the conventions and implicit assumptions of the hand motion language caused problems, along with the lack of immediate, quasi-3D, on-screen visualization. They usually interpreted the signs mechanistically, paying no attention to the indications. They pointed at the problem that understanding of the identification and connectivity signs depends heavily on the correct reconstruction of the presented shape. They often waited for signs such as ‘translate’ and ‘rotate’, which have not been considered for inclusion in HML so far. Their comments on the discernment of the similar signs are very useful for the optimization of the HML for tracking and scanning. Practically all these issues will be carefully addressed in the follow-up phase of our research toward an enhanced and expanded version of the hand motion language.

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