Graspable interfaces for (tele-) cooperative modelling

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ABSTRACT

This article addresses the question, of how graspable interfaces can be used in telecooperation. It describes the BREVIE project, a new kind of CSCW-tool that supports cooperative modelling and retains the advantages of physical shared spaces and tangible models. It supports face-to-face- and tele-cooperation and provides a seamless, integrated environment for groups switching in-between these modes and switching between concrete and abstract representations of models. It serves as example for graspable interfaces and shows the technical basis for extensions towards telecooperation. The paper describes the role of graspable models for shared understanding and participation and a concept for telecooperation, using the idea of merging real and virtual models.

Keywords

Real Reality, Augmented Reality, Graspable User Interfaces, Tangible Interfaces, CSCW, Cooperative Modelling, Teleconferencing, Collaboration, Vocational Training, Pneumatics

INTRODUCTION

Computers provide powerful means to visualise the results of modelling, allowing users to investigate and understand models in ways not possible before. But what about the process of modelling itself? Computer aided modelling requires extensive knowledge of technical tools. Thus modelling becomes a task of tool experts, creating a barrier to cooperative modelling. Moreover, when several people want to manipulate the same model in a face-to-face situation, they are forced to use groupware, which puts them on separate computers.

Graspable interfaces as means for computer aided modelling provide a solution. They allow using the same physical environment and they foster cooperation and shared understanding. As physical models are augmented with digital models we can build mixed models of real and virtual elements. These mixed models can be used to support telecooperative modelling.

Background

Our concept of graspable interfaces pairs real artefacts with virtual counterparts. Users build a physical model while the computer tracks these actions and assembles a corresponding virtual model (see Figure 1). The virtual elements can be used for simulation and, being more than a mere image, can be manipulated by the computer to provide access to various representations and views. The material workspace functions as interface for the virtual model, providing a homogenous interaction space for users and objects in one. Wherever applicable, the output of the virtual model is projected onto the material workspace or provided acoustically. This allows users to observe simulated behaviour or component states in the real modelling context. The projection can also be used to rebuild a previous model, whose layout was saved.

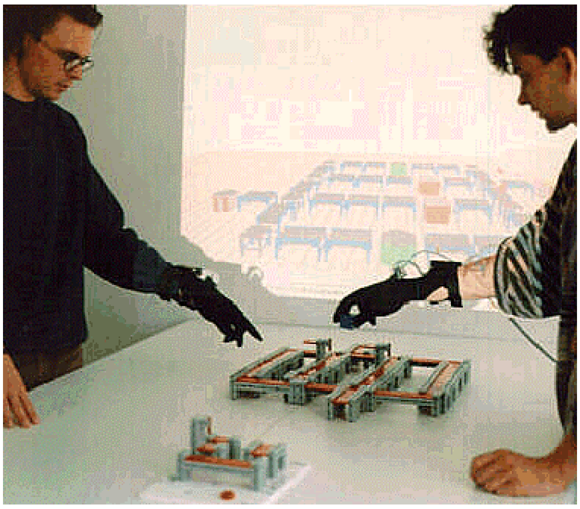

Figure 1: Modelling with Virtual and Real Components

We termed our concept "Real Reality" (RR) as it focuses on real elements as manipulation reference. The basic idea was first published 1993 [1], paralleling the emergence of Augmented Reality. Its original motivation stems from experiences in participatory design projects using experimental prototyping in the domain of factory and production planning [2]. Simulation tools proved to be inappropriate for some participants because of poor usability and abstractness of results. They tended to narrow perspectives because the tacit knowledge of workers could not be included easily into the design process and creative exploring was inhibited. Concrete models proved to be valuable as the basis of discussion in these heterogeneous groups. Results of concrete modelling often had to be painstakingly translated back into virtual models. In addition we found the standard desktop-interface to be an inappropriate metaphor for the environment of factory workshops. The idea of coupling real and virtual models emerged as solution to these problems. The concept provides rich stimulating environments and allows the user to regain sensual experience and switch between different kinds of experiences. We are using this environment for both learning/teaching and for work. The application described below serves as an example and describes the technical starting point for extending the system and the approach towards telecooperation.

Foundation Work

After several national projects [2,3,4], which provided the theoretical background and the basic technology for our *Real Reality* concept we will soon finish the more product-oriented European project BREVIE (Bridging Reality and Virtuality with a Graspable User Interface). The BREVIE consortium consists of three commercial partners (Festo-Didactic KG in Germany, Virtual Presence Ltd and Superscape Ltd in Great Britain), four vocational schools (Great Britain, the Netherlands, Portugal and Germany) and two research institutes (Institute for Work Psychology, ETH Zürich in Switzerland, Forschungszentrum Arbeit-Umwelt-Technik, Universität Bremen in Germany).

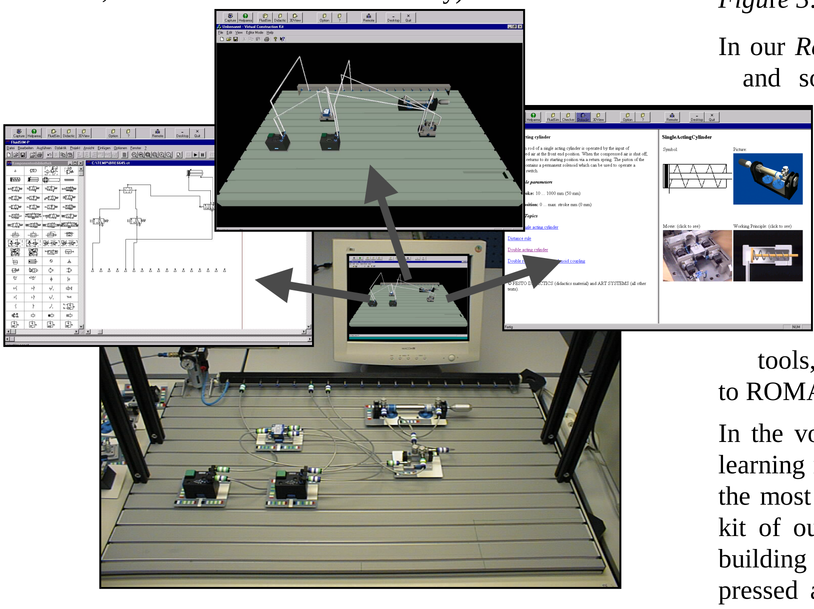

Figure 2: The BREVIE Learning Environment

BREVIE aims at designing, developing and evaluating a new kind of training environment for vocational training in pneumatics. We provided transitions and links between the physical, graspable world of the pneumatic circuit and the abstract world of symbols. The main characteristic of such an environment is to provide transitions and links between two worlds which are currently separated. The link between virtual and physical reality is achieved by a “Universal Graspable User Interface” (UGUI) that enables students to work and learn in both worlds. The UGUI also provides an abstraction layer for different input devices. This allows us to easily replace one kind of input device by another, such as image-recognition, data-gloves, position-tracking-systems, barcode-scanner or combinations thereof, used in some of our other projects. The hardware used in BREVIE has to be affordable for school-budgets. To fulfil this requirement, we chose to use image-recognition to archive the synchronisation between the physical and the virtual model: two low-budget video cameras are mounted above the worktable to recognise colour bar-code labelled elements (see Figure 3).

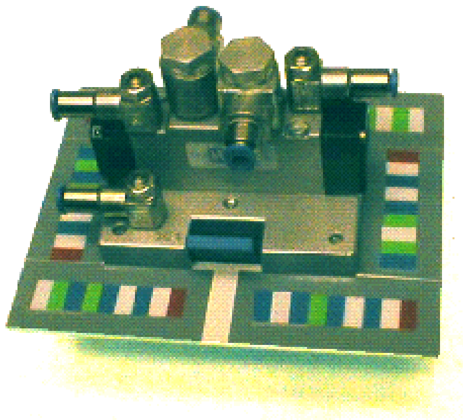

Figure 3: A Pneumatic Element with Colour Bar Codes

In our *Real Reality* systems we integrate several hardware and software components into coherent applications. Since every application field requires a special combination of components we have introduced a highly modular system architecture, which permits us to easily connect existing or new components. The design follows a client-server approach with a *Real Object Manager (ROMAN)* as the central server unit. Other software units - such as the UGUI, simulation tools, 3D viewers or hypertext browsers - are connected to ROMAN via tcp/ip based Socket protocols.

In the vocational training for pneumatics several kinds of learning material can be found. For the project consortium, the most compelling is the popular pneumatic construction kit of our partner Festo Didactic which can be used for building functional circuits. These circuits work with compressed air and allow a very close representation of real production environments. BREVIE extends these construction kits by developing technical links to computer-based learning media.

These automated links between real models and corresponding computer representations provide smooth transitions between multiple views on the same model to support the development of rich mental models. As to be seen in

Figure 2, we have integrated the following views, each with the possibility to interact with the model and to manipulate it:

- The physical model
- The virtual model in 3D
- A symbolic/logical view in a simulation software for pneumatics

In addition, the BREVIE Learning Environment also provides access to multimedia learning material (hypertext, images, videos and diagrams), which introduces the functional properties of the pneumatic parts. The user can request this information right out of the physical modelling context with the help of a pointing device.

This project includes intensive evaluation by work psychologists from the ETH Zürich, comparing learning processes and results with and without media support in four different vocational schools all over Europe. The evaluation of the BREVIE system is divided into two phases: the first took place with an early prototype of the BREVIE system. The second is currently in progress with our new version. The evaluation of the first prototype followed a three-step (pre-test, process phase and post-test) procedure with three different learning environments (Real FESTO components only, pneumatic simulator only and our integrated BREVIE learning environment) were compared. These learning environments differ in the amount of tactile experience with pneumatics components, in the degree of abstraction and the combination of information formats. A 16 hours lesson plan was delivered to 89 students.

We tried to measure the effects on learning (knowledge in pneumatics and practical problem-solving). Despite of several technical problems and limited functionality of our prototype, the BREVIE students gained a higher amount of pneumatics knowledge than the students learning without the aid of computer-based learning media. Nevertheless, we found that the main factors for the learning output were the previous knowledge in pneumatics and spatial abilities. The relevance of practical experience for fast problem solving could be proofed. Based on the positive tendencies shown so far, we expect the results of the current evaluation to more clearly point out the advantages of our system.

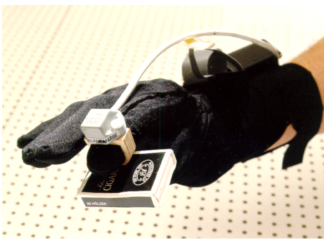

Figure 4: The Magic-Ring

Explorative observations of school lessons by one of the authors, concentrating upon the role of graspable objects, enforced our belief in the BREVIE design. Working with real pneumatic elements proved to be very motivating for students and led to curiosity regarding the internal functioning of components. We could also observe emotional responses. When the teacher used computer tools not coupled with the real circuit, we observed that one person kept working on the real circuit while the other assisted in asking the computer for help. This soon led to the second person playing around with the computer system. Thus computer tools must be tightly coupled with the task. We also observed, that the large pneumatic tables seemed to invite collaboration, as nearby groups often watched their neighbours and helped out of their own accord.

We have also investigated different application domains (e.g. factory layout and conveyer belts in the project RUGAMS), alternative interaction techniques and diverse input devices. By using tracking-systems in conjunction with data-gloves or a finger ring with a touch-sensor ("Magic-Ring", see Figure 4), we are able directly to detect the users actions and to analyse them with a gesture recognition system. When a grasp action is detected in close vicinity to an object, its virtual counterpart starts to move in accordance. To keep real and virtual model synchronised, all real objects must be taken from a defined starting position. We use an "object box" which holds all possible types of elements. Experiences of the EUGABE project in building a learning environment for circuits using datagloves are described in detail in [3]. Using image recognition of barcodes, as in BREVIE, solves some problems we experienced with the detection of tubes, respectively with detecting the position of tube ends and discerning if two ends belong to the same tube. This had to be dealt with by requiring users to finish positioning a tube before using another element. Yet gesture recognition allows us to keep the physical and the virtual model synchronised in real-time and to experiment with additional functionality such as using gestures as commands, virtual keyboards and programming by demonstration. Rules for the behaviour of conveyor belts can be demonstrated manually by moving elements. These rules are automatically generated into CNC-programs (Computer Numeric Control) [4]. The result can be evaluated by running a simulation, which is projected from above onto the workspace. Brightly coloured objects seem to move over the conveyors, giving concreteness to the simulation and retaining the role of the physical workspace as basis for discussion.

USING REAL REALITY FOR CSCW

Our concept can be interpreted not only as an interface technique, but also as groupware technology for modelling tasks. In the next sections we will describe its value for face-to-face cooperation and then extend the concept to support distributed cooperation while keeping the affordances of tangible interfaces. This implies new usage scenarios and technical inventions. The common property of these scenarios is that the environment supports certain kinds of cooperative behaviour without enforcing them. A technical tool cannot force equality and participation, they must be negotiated. We believe that in cases of unequal power distribution or high conflict a human facilitator with sensitivity and inventiveness in the appliance of moderation methods is indispensable.

Using RR in Face to Face Cooperation Scenarios

Many researchers agree on the importance of face to face communication (as richest possible medium) for situations with high potential for conflict or for starting cooperation between strangers [e.g. 5,6,7]. This holds for many design situations and implies a need for tools that allow undisturbed face-to-face discussion. Most groupware systems have been designed for telecooperation purposes. When groups want to work simultaneously on one object, they are forced to individually work at separate computers. This holds true for most Group Decision Support Systems as well, which tend to lack support for conversation and underestimate different perspectives and ontologies of participants [5].

Up to now, only few efforts have been made to support face-to-face discussion without constraining human interaction. Notable are projects like Roomware [8], MITs Tangible Bits [9] or BUILD-It [10] which enable users to work in habituated ways with computerised (often tangible) tools, to communicate unmediated, which provide huge interaction spaces and thus visibility and don't interfere in communication processes. Graspable interfaces like RR and some of the systems mentioned above share characteristics that play an important role for face to-face-cooperation. In the following discussion of these characteristics we concentrate on tangible models as used in RR. We abstract in large parts from technical implementations.

Concrete physical models afford a wide range of approaches to modelling, including playful, intuitive and experience oriented ways of thinking. They can be used by people of all qualification levels. This is especially helpful for learners and heterogeneous groups. Taking active part in modelling is not confined to tool experts, who acquire a model monopoly, but is possible to all experienced with the task at hand.

The tangible objects allow for "natural" interaction and don't interfere in human communication. In a physical workspace people can effortlessly see the entire workspace and everyone in it by peripheral awareness. It is easy to shift attention from one area to another or to someone talking. People see the actions themselves, announcing movements and results of manipulation. Deictic actions can be used to communicate and to attract attention. Proxemics also plays an important role. The objects are a shared reference for communicating. The material workspace functions as "shared interaction space" and "shared social space" [10,11] which fosters communication and shared understanding. Verbal and non-verbal communication is perceivable. A physical shared space also produces the effect of social nearness. Some philosophers argue in favour of this point describing communication as a process of individuals practising (bodily) presence (german: "Präsenz"), whereby bodily attendance produces a distinctive atmosphere), and mixing it with the presence of other individuals.

The physical shared space of RR is augmented by a range of digital representations (simulations, VR views, abstract views etc.). Following our approach these visualisations must be integrated into the environment, i.e. projected onto the workspace, onto large wall spaces or at least onto a screen in close vicinity. We have implemented all of these possibilities in our projects. BREVIE up to now uses the last, while RUGAMS highly exploits the first solution for merging graphical simulations into the physical environment. To support activities in the physical workspace, it is important to provide good visibility for all group members and easily learnable actions to manipulate these views. Thus, there results a shared physical space for people, physical objects and visual representations.

Many approaches to cooperative or participatory system design start with building up a dictionary of definitions of important words, which serve as basis of a common project language and to identify important objects. This assumes that people are able to explicate and to give names, leaving out tacit knowledge. Parts of tacit knowledge, especially on processes and movements, can be shown and defined by concrete demonstration, as our experiences in factory planning showed. Learners profit from concrete models as well, as they do not know or remember names of things, but may be able to recognise and manipulate them.

Concrete models can act as anchor, as tangible symbol, to be pointed and acted on. They can be understood before a common vocabulary is found. Thus they are a help for developing a common language in being kind of a "boundary object" [12]. In the RR approach, the physical elements can be chosen to be highly realistic (e.g. Fischertechnik conveyor belts, pneumatic valves), giving way to vivid but shared imagination, or to be very abstract (e.g. wooden bricks), leaving space for individual views.

The possibility to explain things by showing or manually trying them out eases the strain to be verbally fluent and thus eases cognition. The virtual model can act as memory - it can provide a playback of the modelling process which can then be analysed - or it can provide a simulation of the modelled scenario, enabling users to see the result of the interplay of their decisions. It also provides passages in-between representations. In terms of distributed cognition tangible interfaces are open tools, on which actions are observable by bystanders [13]. They afford re-representation across media, as users can make a design in an intuitive way and then switch to digital representations of it. Within the RR concept, for example, users assemble a conveyor layout from Fischertechnik® elements and demonstrate rules for the movement of containers. Afterwards they can analyse the model and its behaviour in 3D representations as well as in abstract representations like SIMPLE^{++}.

Further goals and possible extensions

Graspable interfaces should retain the benefits of real interaction spaces while obtaining the possibilities offered by digital media. The CSCW literature offers many demands that can be applied to the kind of mixed environment we describe. Two of these, not structuring interaction using false models of communication, but relying on the establishment of social protocols [5] and supporting awareness [14] are easily met. Interaction is structured only lightly by providing a shared physical environment, which serves to focus attention. A change of perspective can be attained by physical movement or by selecting an appropriate representation of the virtual corresponding model, i.e. in BREVIE choosing a video, watching an animation of the inner functioning of elements or simulating the abstract circuit.

Other goals are not met yet. More effort must be put into the administration of different drafts of models and versioning. Users should further be able to annotate models in order to explain design decisions, e.g. by putting a physical symbol onto a spot and then speaking into a microphone or typing. There should be support for the ad hoc development of new kinds of views or representations. How to support splitting up into subgroups, individual work and merging the results together into one group needs to be considered [8]. Subgroups may need own workbenches and individuals may want to ad-hoc declare part of the table as a private area for a while. The virtual model should support building a virtual model out of several drafts. Based on the projection of the resulting model onto the workbench the group could then build the real model which integrates their ideas.

UTILISING THE ADVANTAGES OF GRASPABLE INTERFACES IN TELECOOPERATIVE SCENARIOS

How can we handle scenarios, in which single participants or subgroups are locally separated but want to work together? To support these scenarios, a facility for telecooperation is needed.

When extending the functionality of our modelling table from a "same-time, same-place" to a "same-time, different-place" telecooperation tool, the physical shared space rises new problems, that do not exist in common, pure computer-based groupware.

Integrating (tele-)modelling with graspable interfaces

When integrating telecooperation functionality into a physical interaction space the following difficulty arises: how to protect the user from being forced to pay more attention to what happens with the shared virtual model through remote manipulation than to the physical model? This would have the negative effect of loosing the physical model as the reference model and disturbing the physical interaction space since the virtual model can become more actual than the physical one by means of remote actions.

Therefore, a careful design concept for telecooperating with physical interaction spaces is needed:

The basic idea is not to synchronise physical models via projection or robot arms but to divide the overall virtual model into submodels and associate each physical model exclusively to such a submodel. These submodels can be seen as exclusive aspects of the overall model. The resulting advantage is that the users determine their (sub-)models only through their own actions in the physical interaction space. Therefore the users aren't forced to pay much attention to remote manipulations. This means that the reference model stays in the physical world.

The concept of dividing complex models into exclusive aspects respectively submodels reduces the necessity of getting into direct contact with remote participants during submodel specific problem solving. In such a telecooperative environment the use of teleconference functionality will be concentrated in those distinct development phases where submodels are related to other submodels. This happens usually during the discussion of a system architecture, definition of interfaces between components or when completed components are integrated. Such phases can be supported by telecooperation functionality and on the other hand by providing explicit technical support for face-to-face meetings.

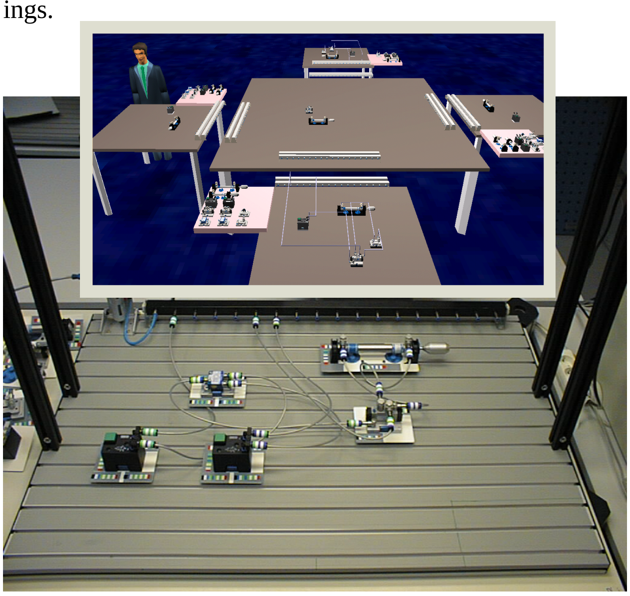

Figure 5: Working with Submodels

Figure 5 illustrates the extension of a modelling environment towards telecooperation and submodels. Each submodel with a physical counterpart is allocated to one of the four outer tables – the table in the middle is supposed to contain purely virtual objects. The virtual submodels with a physical counterpart are automatically synchronised via our UGUI software.

Using this idea for the concrete application from our BREVIE project the following scenario can be realised:

A teacher or an external provider of learning material defines a complex system or plant and loads it on the central virtual table. The building blocks of the overall model are abstract representations of different aspects, for example electronic, pneumatic or mechanic units. The tasks of the building blocks can be either directly conducted from the model context or are attached to them as text descriptions. During lessons, student groups can pick separate aspects, move these submodels to their physical modelling tables and solve the specific problem. Afterwards, implemented submodels can be moved back on the central virtual table in terms of a system integration.

With a set of predefined viewpoints users can navigate through the virtual model, get close-ups for each submodel or see an overview over the complete model. Since we use the same mechanisms of free navigation and navigation with the help of predefined viewpoints like in our face-to-face scenario, there is no extra learning effort for users to inspect other submodels.

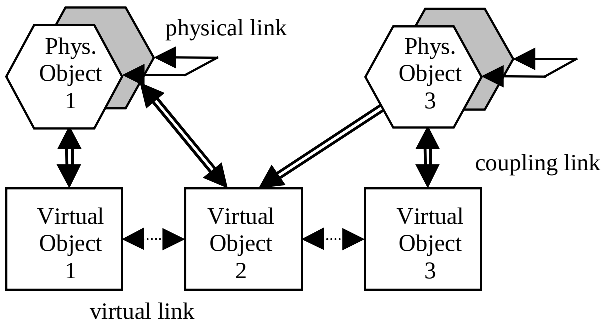

Figure 6: Coupling Physical and Virtual Reality

For connecting arbitrary submodels with each other, it is an important technical requirement to be able to connect physical objects to virtual ones and remote physical ones. This is achieved by our new "Merged Reality" technology, which is based on special pneumatic and electronic connectors with the ability of sensing and emulating state changes. This coupling mechanism (see Figure 6) provides the possibility to isolate every physical component of a system from its surrounding and connect the cut off connections (pneumatic tubes or electric wires) to a computer controlled physical process emulator. This emulator is able to generate all necessary phenomena to make the isolated component behave as if it would be in a real environment. The implementation of such Merged Reality connectors is one of the main topics in our current research project DERIVE (Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service).

The concept of collaborative modelling with tangible objects and connectable, distributed submodels is useful for both top-down and bottom-up design:

Top-down: The group defines packages and interfaces between them. Each package needs a more or less abstract representation in the virtual world and – if the system design takes place in the physical interaction space – in the physical world. This outline of the overall model can be moved onto the central virtual table. Afterwards, the users can pick single packages from the outline, associate them with their physical modelling tables and treat them as separate aspects of the overall problem. If completed, the submodel can be tested with other submodels and can be moved back into virtuality as an implemented package.

Bottom-up: The participants of the modelling group start developing independent submodels and connect them later on – directly via our Merged Reality connectors or by moving the submodels onto the central table and test the overall system with a simulator.

In addition, it is possible that users build up alternative solutions for the same problem and use the modelling environment for comparing and discussing the alternatives.

As stated above, the division into submodels reduces the need for telecooperation functionality during problem solving. Nevertheless, such functionality is necessary if submodels are connected, compared or discussed. In these modelling phases the users need - despite spatial separation - the feeling of being really located in a common, virtual modelling environment. Thus the users require the perception of virtual presence, which procures them the sense of participation and involvement [15,4]. Since we want to support both synchronous and asynchronous modelling, we need different kinds of cooperation mechanisms.

For synchronous modelling the integration of chat, video- and audioconferencing [16] is appropriate. In addition, it is also helpful to view the other users actions as corresponding avatar movements [17].

Concerning asynchronous cooperation mechanisms the design includes repository respectively version management functionality. Old versions can be shown as distant table groups in the virtual world with additional predefined viewpoints to navigate to these versions. In addition, it is necessary to have the possibility to attach version labels with text descriptions or audio files to submodels and versions.

The described concept for an extension of our tangible modelling environment aims to be an *integrated concept* for modelling with graspable interfaces alone, face-to-face in a local group and telecooperatively with remote participants or remote subgroups.

Our approach to telecooperative modelling in merged reality applications thus leaves the reference of submodels with physical counterparts in the physical world. Other approaches – for example trying to synchronise distributed models via projection or automatic model rebuild with robot arms – have the disadvantage that they move the reference to the virtual world and lead to unintended and unexpected effects for the user of the physical model.

The advantages of handling tangible objects are extended with telecooperation functionality in a way without disturbing the shared interaction spaces of local users or subgroups. It is not our goal to have people work entirely with the virtual representations across distance. Because the shared interaction space remains intact as reference, each participant can use his physical submodel in a modelling session without paying much attention to the virtual model since the remote users cannot manipulate it. Every participant is restricted to working in his own physical submodel.

DISCUSSION

Extending the concept of graspable interfaces to telecooperation and thus into virtuality might seem contradictory at first glance. This section covers related questions, focusing on the role of graspable models in the telecooperative scenarios and proposing how the approach can be used as an integrated environment.

Considering the entire dispersed group in the telecooperative "distributed model" scenario, the physical shared space (offering many valued affordances) gets lost. But local subgroups still have their local physical submodel. Thus we loose advantages for cooperation in the entire group, but not for local subgroups who focus on their submodel.

Users needs to interact with the overall, virtual model only if they want 1) to move a submodel from virtuality to reality or vice versa, 2) to look at or to interact with other submodels, 3) to get into contact with remote participants, or 4) to connect their submodel with other submodels. Only during these actions the user needs to extend his/her physical interaction towards the virtual world. In this case a virtual/social presence in the shared virtual workspace is needed. These actions are optional and do not hinder the look and feel of modelling within the physical world.

The three scenarios are not competing alternatives. Following the requirements for seams in-between working media, they can be combined to form an *integrated environment*: A group can start by meeting face to face and building a real model. Once they are comfortable and have built some common views and shared goals they decide upon a division of labour. At home they can continue using the same modelling environment, enhanced with telecooperation features. When the entire group meets again, the modelling system can be used to access and view results of subgroups. Some of these (virtual) models may be rebuilt to continue modelling with.

Can looking at remote models in the teleconference mode provide the same information as watching real models? If a physical model has a distinct look and feel, this is not possible. Thus there needs to be compensation. In the case of functioning pneumatic elements virtual representations will not be as real even in the best immersive VR environment, as they involve mechanic power. To enable full deictic interaction with models we would need such a VR environment. Our environment can not simulate or substitute for the physical model, but it can help getting more information. If there is a virtual submodel which cannot be understood, users can select it to rebuild it on their physical workbench to experience its look and feel. They can test it's functionality via simulation or ask the creator. That's where teleconferencing comes into play.

While stressing the advantages of real models we are aware of those of virtual models. They can be much more accurately modelled, because it is easier to change i.e. colour or size. VR models can easily be duplicated and simulated, be extended with further information or pre-existing models. With real physical models all of this means a lot of work. Thus physical and virtual models are counterparts which should not be seen as pro/contra alternatives, but as complementing each other. The physical model is valuable especially when we can use functioning elements (i.e. pneumatics) and it is valuable as modelling interface with easy handling. Mixed models can help coping with complexity as they allow to build up parts (submodels) to concentrate upon while shoving the surrounding to a virtual model. Other factors which can help to determine whether a RR environment will be helpful for modelling include the task and the user group.

CONCLUSION

Telecooperative modelling does not necessarily restrict users to only work with graphic representations and to use mouse and keyboard to interact with models. This article shows alternatives, which retain many advantages and affordances of shared physical environments.

Using our approach, seamless systems which support face-to-face as well as distributed work phases, can be built. Local groups keep a shared physical space and do not need to change interaction with models, unless they want to communicate with remote members.

Based on existing work, which supports face-to-face modelling and merges real and virtual representations, we explained how to extend the approach to telecooperation. This will be implemented in a forthcoming project.

RELATED WORK

Related Work stems mostly from Augmented Reality Research [9,10,18]. The Roomware concept allows natural interaction in physical environments [8], concentrating on pen-and-paper metaphors. A deliberate mixture of telecooperation and tangible interfaces seems scarce. [19] use digitally controlled, physical surrogates for awareness and causal interaction with distant team members plus audio/video connection. [20] concentrate on pure tactile presence, using a magnetic chessboard to play distant chess, providing a kind of "ghostly presence" as elements move.

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