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Author(s):
Ganser, Christoph; Kennel, Thomas; Kunz, Andreas

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Digital Support for Net-based Teamwork in Early Design Stages

Christoph Ganser, Thomas Kennel, Andreas Kunz
ICVR – Innovation Center Virtual Reality
Swiss Federal Institute of Technology Zurich
Zurich, Switzerland
(ganser | kennel | kunz) @inspire.ethz.ch

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Abstract
The early stages of the product development process are the most important ones. Decisions made here affect the success of a new product. Due to the complexity of products, a multidisciplinary knowledge is required. In the globalized world the company’s internal and external experts are spread all over the world. Time and cost pressure impedes teamwork with personal attendance. As a result, personal meetings are strictly limited and teamwork is often reduced to e-mail or phone communication, combined with shared document repositories. Especially for these early stages in product development there is no suitable support by means of information technology. Creativity methods like brainstorming have shown to be valuable in this phase. But in order to support them, it is very important not to influence the user’s creativity by handling an intricate computer system. Thus, we introduce a system, which allows a net-based collaboration that goes far beyond today’s existing technology. In addition to typical audio and video communication, intuitive interfaces like pencil or eraser allow to work simultaneously on a shared digital workspace. Therefore the presented system does not only support net-based collaboration, but also supports co-located teams to perform team sessions in the early stages on an intuitive digital basis.

Introduction
In the past decades, big effort was done to support the product development process (PDP) by means of information technology. Technologies like 3D-CAD, PDM, ERP, or other systems lead to significant savings in time and costs. Their usage is widely accepted in those phases of the PDP, in which the product’s geometry is defined. Especially for the geometry definition phase, many specialized tools for the support of a development team exist, as shown in Figure 1.
Figure 1: Today’s limits of IT-support [1]

Figure 1 also shows the principle tendency to extend the IT-support to other stages of the PDP. This means on one hand to support also the very early stages of product development, but also to realize a continuous knowledge-based PDP. If all knowledge on the product or process from prior steps in the PDP is available, a more reliable basis for current decisions is given. However, today’s usage of information technology is mainly concentrating on later stages, the very early stages like creativity or brainstorming phases are not or only insufficiently supported. Thus, many of these very early phases are still performed paper-based, although almost all subsequent steps are on a digital basis (see Figure 2) [2]. This results in a gap in the logical, IT-supported workflow.

Figure 2: The gap in IT-support within the product development process

The paper-based working method requires meetings with personal presence for the interdisciplinary teamwork. Necessary participants as experts or members of other
business units are often not on site and spread all over the world. In order to reduce the expenses for such meetings, their amount is limited and spontaneous discussions are not possible anymore. This is a critical tendency, since in particular the early stages define most of the relevant criteria of a future product. Thus, the necessary innovation phases are drastically reduced. The innovation phases can be characterized by the following possible situations:

- Teamwork in large groups, e.g. project meetings,
- Teamwork in smaller groups, e.g. brainstorming sessions,
- Presentations and knowledge transfer.

The goal of any IT-support for the early stages of the product development process is to support such phases with physical presence, but also the work in virtual net-based teams.

**Methods supporting the very early phases of the PDP**

As shown in Figure 2, the creative phases of a PDP can be subdivided in 3 processes, which often run through iteratively before the following phase predicates on the results.

- the investigative process
- the creative process
- the evaluative process

The investigative process describes the acquisition and collection of all information concerning the problem. This typically occurs by market-analyses, interrogations and desktop-research as patent- and literature research, analysis of known technical systems, etc. One or multiple people can perform the tasks of the investigative process independently and in parallel.

Within the creative process, ideas are impulsively generated. The goal of this phase is finding as many novel solutions for a given problem as possible within short time. Therefore, often so-called creativity-methods are used. Well-known methods are brainstorming and brainwriting, which can be practiced in varying manner depending on the problem and the configuration of the team. Teams of 5 to 7 attendees, collaboratively generating ideas, can achieve best results. Due to insufficient support by means of IT, this creative group processes are mostly performed in an analogue manner. This complicates taking minutes, and thus many good ideas and important Meta-data are lost. Also a physical presence of all participants at one location is necessary.

In the evaluation process, the plurality of ideas has to be filtered for the subsequent phases. For supporting this process, a lot of different methods and applications are available. Like the investigative process, single users can fulfill many tasks as they base on objective values and generate the facts and criteria for later decision making. Most of the popular methods base upon spontaneously writing and sketching ideas on cards. Gaining insight in the cards and so in the ideas of all other participants feeds the individual creativity and enables associativity. Therefore, simultaneous interaction of all participants with the system is essential. All ideas are kept digital at the moment they appear. The dynamics of teamwork is not disturbed and taking minutes of a creativity session as well as the further usage of data is significantly simplified. The integration of net-based team members should be as natural as possible to afford a common group dynamics. The representation of the remote participants takes place at the point of action (Figure 14). Therefore, the described system facilitates a real and efficient teamwork for local and distributed teams in a natural mode.
Contribution
We introduce an IT-support for the early stages as well as first realization steps. After completion, all components will shape the so-called virtual project room. This room has a physical presence and a virtual presence as well. Thus it supports local teamwork with physical presence, but also the work of net-based teams in an IT-environment.

For the IT-support of the early stages of product development, the following aspects have to be taken into account:

**Disappearing Computer**: The presence of a computer in its typical shape influences a creativity session: Each idea will be immediately checked for its novelty by browsing databases, E-mails are checked, or other tasks are done. This slows down the meeting and consequently also reduces its efficiency. The digital acquisition of ideas by using visible computer technology also induces final solutions and therefore it hinders the creativity and spontaneity of the participants.

**Intuitive Usage**: Creative ideas are very inconstant and thus have to be noted down or sketched very fast and intuitively in order to further use them in the team session. This process is slowed down or impeded by using conventional interfaces like mouse, keyboard, and software with a conventional interface. The fast capturing of ideas, e. g. by sketching, allows the user to externalize his thoughts, rethink them and explain them more easily to the other team members. Supporting this process is the prerequisite for a mutual stimulation during a brainstorming session and is only possible, if the IT-system can be intuitively handled. To operate software having lots of menus and icons with mouse and keyboard increases the cognitive load on the user.

**Simultaneous Working**: Typically, creativity sessions are not moderated and frequently people work in parallel. Thus, the supporting IT-system should also allow a simultaneous input by multiple users. Here, a change is required from the normal PC-metaphor (personal computer), which typically only allows one single input a time, to the CC-metaphor (Collaboration Computer), which allows the group members to work simultaneously on a shared display.

**Collocated and Net-based Working**: All the advantages of a digital support can only be used, if not only a collocated team with physical presence is supported, but also net-based team members could be integrated. Here, the system should give the full interaction capabilities of a local team member also to a team member in the net. Besides sketching on a shared data model, a high quality audio/video conferencing solution is needed. This allows the participants of a meeting to exchange more information. Mimic and gesture are as important as the spoken communication. As teamwork is about social interaction, the interpersonal layer should not be underestimated.

The better the above points are fulfilled, the more the members of a team will accept to replace the paper based working method by a system allowing teamwork to be performed on a digital basis.

In the field of human computer interaction (HCI), there are two interaction principles, which offer a very promising basis for IT-supported teamwork in the early phases of the PDP. This is on one hand the concept of Tangible User Interfaces (TUI) [3], and on the other hand the concept of Single Display Groupware (SDG) [4].
The research in TUIs roots in the criticism of the WIMP\(^1\) user interface concept. For thousands of years, humans used many specific tools to complete the tasks in their lives. Today these mechanical skills lie idle when computer users interact with a keyboard and a mouse. The solutions proposed by the TUI research community are manifold. Simple solutions were proposed like the extension of the general two dimensional mouse pointers to a multitude of pointing devices directly used on the display to enable a direct interaction. These input devices serve as physical handles to the digital content on the screen. The use of multiple interaction devices in one application further allows the user to interact bi-manual with the application. TUIs also introduced the use of multiple specialized interaction devices denoting their function through their physical shape. These devices are called physical icons (Phicon). An example could be a device shaped like a lens, when placed on the computer display, it magnifies the underlying digital content.

TUIs’ focus is on the rich interaction of a single user. The introduction of multiple input devices bypasses the single user concept of current operating systems. This sets the foundation for concurrent, co-located group interaction.

SDG is focusing per definition on multiple inputs from multiple users on a single display per time interval. However, no specialized input devices are used, but mainly general pointers and keyboards. By providing an own set of input devices to every user, there is no need to share them. Turn taking in a discussion can be treated like in a normal discussion using the intonation in our voice, mimics, and gesture. Who doesn’t know situations in which somebody wants to show something to a group on a computer, but has to wait until his comrade handed over the input device? By using one display as a shared output channel, users have the advantage of being able to explain their thoughts to the other participants without any effort. SDG is currently realized by involving multiple computer mice or multiple laser pointers\(^5\) [6].

The basic idea of the system introduced here is to use both interaction paradigms mentioned above and to realize a new interaction space, which combines the intuitiveness of TUI with the SDG’s capability of simultaneous interaction (see Figure 3).

![Figure 3: New group interfaces based on TUI and SDG](image)

**Related Work**

Important Graspable User Interface (TUI) concepts have been introduced by [3]. The paper shows the advantages of providing the user multiple pointers called “bricks”. Unlike mouse pointers, the “bricks” feature the recognition of the orientation and enable the user to interact directly on the display. They can be attached and detached from digital content on the screen. “Bricks” also allow bi-manual interactions of various operations (like selection, bending …). Multiple bricks enable the user to control an underlying application faster, than using graphical controls and

\(^{1}\) Window, Icon, Menu, Pointer
the mouse. The project used a cable bound 6DOF tracking system to detect the users’ interaction.

In [7], a TUI is presented to interact with a geographical visualization system. The system uses various specialized interaction devices, designed as a graspable replacement for conventional widgets. The devices use their specialized shape to “explain” the user their function. For example a physical icon (Phicon) shaped like a real building standing in the displayed landscape allows the user to move the map by moving the Phicon. A device shaped like a big lens allows the user to visualize aerial photographs on the area coverd by the lens. The project used a 6DOF tracking system and alternatively a 2D computer vision system running at 7 Hz.

Sensetable [8] is used for an interactive tabletop system for interaction with simulation applications. The system uses “pucks” as input devices. Onto the pucks modifiers can be plugged. Beside ID modifiers, the puck also supports a dial. The technology uses two modified Wacom Intuos graphic tablets with a gap of 3.5 cm in between for sensing multiple interaction devices. The update rate of the system is less than one second. If only one device is touched, it can be tracked at a higher refresh rate.

Caretta [9] is a system for face-to-face collaboration. The users can collaboratively plan a city. For the planning task a board with an array of RFID reader underneath is used. By placing objects with RFID tags onto the board, the city plan can be modified. Additionally, the users can interact using their private PDA. The study also showed the value of simultaneous interaction in collaborative work.

Klemmer et al. [10] use a back-projection SMARTboard™ to manipulate physical Post-Its and draw virtual connections between them, allowing web-designers to build up a web-site hierarchy. Besides the single user touch screen, it uses two additional cameras, one tracking the Post-Its from the backside of the SMART board and another acquiring the physical sketches on the Post-Its. The system also explored remote collaboration.

An environment for creativity and innovation is presented in [11]. The system consists of various room elements like wall, chair, and table with integrated information technology. It also features a mechanism for transporting information between the different objects. Resistive touch screens are used on the wall and the table allowing one single user to interact at a time.

A user study on SDG can be found in [4]. It compares the usage condition of users collaboratively sketching with an individual mouse on a shared display, with the situation in which the users have to share a mouse for sketching. 85% percent of the participants thought multiple input devices are easier to use, and 98% prefer this work condition. The main advantage is seen in the simplified scheme for turn taking (49%) and the possibility to work in parallel (35%).

An outstanding multi-user input technology for SDG is DiamondTouch [12]. It allows the users to interact with their body (finger, hand, and arm) on a horizontal front projection display. The detection of the user’s finger is realized by capacitive sensing. A high-frequency signal is sent from the interaction table through the user’s body into the receiver, which is integrated in the chair. The interactive surface measures 42 inches in diagonal. Besides the users’ body, a cable-bound pen connected to a separate receiver than the user can be used as an additional pointer. Many projects have worked with laser pointers to allow interaction on a large display at a distance. The use of laser pointers requires special interaction techniques as the device does not feature buttons and states [13]. Dwelling has been proposed to

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2 Widget: a control element in a graphical user interface
signal a left button event, where as [14] added wireless mouse buttons. Chen and Davis [15] used laser pointers to allow multiple users to interact on a high-resolution tiled display. In Oh and Stuerzlinger [16] a system is described that enables three users to simultaneously interact with laser pointers on a front projection display. The devices are cable-bound. In order to identify the devices they are turned off and on again every third frame. Many products for interactive surfaces are on the market. But most of the products are for presentation scenarios in which only a single user interacts with the digital whiteboard. A pioneer work in research in this area was LiveBoard [17] and its software suit ‘Tivoli’ [18]. The system consists of an LCD projector and active styli with four distinct states. “The pen emits a beam of optical radiation which is imaged onto a detector module located behind the screen near the LCD. After some signal-processing, the digitized pen position readings are sent through a serial port to the computer.” The Tivoli paper envisions simultaneous multi-user interaction and remote collaboration. Commercial single user systems can be categorized by the technology they use. Optical systems are Canon LV-DP 10/11 [19], SMARTTech DViT [20]. Resistive touch screens are used by older SMARTboards™ and others [11]; ultrasonic tracking systems are e-Beam [21] and Mimio [22]. Six-Degree-Of-Freedom (6-DOF) tracking systems offer additional degrees of freedom for pitch, yaw, and elevation of multiple tracked devices. Besides many advantages, they tend to be very expensive. As our setup is thought to be crowded with many users and objects, we do not expect 3D ultrasonic tracking to work properly because of shadowing. Our first setup consisted of an optical tracking system [23] mounted on the ceiling above the interactive table. Due to minimum distance between the system and the tracked volume, it could not be mounted under the table. The styli consisted of a plastic tube with the reflectors for the tracking system attached to it. The states of the buttons on the tube (tip and additional button) were transmitted by the printed circuit board we took from a wireless mouse and attached it to the tube. The setup turned out to not be suitable for the interactive table setup, as the users were in the optical path and occluded the markers. In addition, the optical tracking system requires three markers to be fully visible, which was not the case with an upright position of the pen (see Figure 4).
As we have seen in the previous paragraphs, many input technologies for interactive surfaces have been created. Nevertheless, only very few systems can support simultaneous interaction of multiple users. Even fewer systems feature detection of the input devices’ states (like buttons). Input technologies for tangible user interface usually only support update rates below 12 Hz and their principle mode of operation often restricts the construction of input devices.

This encourages us to develop our own input technology, supporting input from styli and TUI. The system should enable the creation of a variety of input devices as described in the next paragraph.

**Technical Realization**

In order to realize the above requirement of a single interaction space with multiple simultaneous interaction devices, the system should be capable to capture the devices’ positions on the workspace as well as their identity. Furthermore, additional functions of the devices should be identified, like color and line width for instance. All information should use the same transfer medium in order to have a definite relationship between the devices’ locations and their identities as well as additional functionalities. Figure 5 shows the principle set-up of the system.
Figure 5: Principle set-up of the system

The system bases on an optical infrared data transfer and on an optical tracking as well. Since only 3 degrees of freedom are required (x- and y-coordinates, rotation around z-axis), the chosen principle offers the highest flexibility and resolution. All information, e. g. generated sketches, are back-projected from underneath the table onto the interaction space. Using an IR-LED as an interrogator, all devices on the interaction space are triggered and reply with their identification and status. This is done with a binary IR-signal as shown in Figure 6.

Figure 6: Structure of binary IR-response

The 5-bit word is separated into two parts, 3 bits are used for the identification of the device, and the other 2 bits are used for each device’s status. Since ‘000’ is not used for the identification, 7 different devices with 4 different statuses can be recognized. The recognition is done by a 60 Hz Firewire camera, which is applied with an infrared filter and placed underneath the table. The location of the received IR-signal on the CCD chip gives information on the device’s position on the workspace. Capturing and interpreting 5 subsequent frames coming from the camera gives information on the device’s ID and status. This kind of object recognition requires an exact synchronization of all components, which is done by the synchronization unit shown in Figure 5.

In order to properly respond to the interrogating IR-signal, all devices are active and need certain intelligence. Thus, a microprocessor is integrated into all devices, which processes the interrogating signal and generates the corresponding response. Figure
7 shows the printed circuit board with the SMD microprocessor, which is integrated in each device.

![Image of device's electronics](image)

**Figure 7: Device’s electronics**

The printed circuit board is the base element, which is integrated in each interaction device. However, when realizing the other interaction devices, it turned out that beside the pencil all other interaction devices require also the orientation beside the position information (e. g. for handle, ruler, color pot, etc.). Here, the acquired camera image is not only used for detecting the position and ID of the devices, but also their orientation. This is done by detecting the relationship of IR-LEDs with the same ID. From these relationships, the orientation and other functions can be derived. The developed input technology is explained in [24].

In order to realize the local teamwork as intuitive as possible, different devices were designed, which we will introduce in the following paragraphs.

1. **Pencil:**

   Teamwork is mainly characterized by the dialog between the team members, which is supported by additional sketches and written annotations. For that reason, we realized multiple pencils as shown in Figure 8.

![Image of realized pencils](image)

**Figure 8: Realized pencils**
Figure 8 clearly shows the infrared receivers (dark areas), which are required for the interrogation of the device. The response is given by the IR-LED, which is integrated in the pencil’s tip. The LED is also used for the detection of the pencil’s position. The pencil has three different statuses (bits 5 and 6). The LED in the tip can activate a micro switch button, if it is pressed onto the workspace’s surface. Here, the known metaphor is realized, that a pencil is also often used to point at certain objects. In this case, the pencil’s tip is not pushed and the pencil is used to move a personalized mouse pointer for pointing at objects. Actually, the mouse pointer is not required for a local teamwork with collocated team members, but it might become important as soon as net-based team members will join the session. The mouse pointer is shown in Figure 9.

![Figure 9: Pencils in the ‘hover’-mode when controlling personalized mouse pointers](image)

In order to write and sketch, the pencil’s tip is pressed onto the surface of the workspace and the pencil is switched into the ‘write’-mode. In addition, the pen has a rocker switch, which can be used to recall additional functions, e. g. changing the line width.

Using the example of the pencil, it becomes clear that multiple devices can be detected simultaneously (see also Figure 9). In the case of pencils this is equivalent to the same amount of users, working with the system at the same time. However, capturing multiple devices simultaneously could also allow that one user handles multiple input devices, as this is typical for the following interaction devices.

2. **Ruler:**

The ruler is another interaction device that was realized. This device has several functionalities in two basic operation modes that will be explained here more in detail. The two basic operation modes are visualized by a green back-projected ruler or a red one, respectively.

Without pressing the black control box at the end of the ruler downwards, the device is in the green ‘ruler’ mode (Figure 10). The ruler has a slider (see Figure 10), which addresses the known metaphor of a caliper. Thus the user immediately knows, that he can measure distances with this device. However, the device needs to be calibrated first and the resolution is only sufficient for a rough estimation of distances and sizes.
A pen is associated and dissociated with the ruler by touching its edge (see Figure 10). A associated pen will draw only draw straight lines. Here, the well-known metaphor is realized that a ruler can be used for drawing straight lines. In addition, it is also possible to draw straight lines even if the pen does not directly touch the ruler. This is in particular useful if hatches have to be drawn. The ruler also offers the capability to draw straight lines under certain snapping angles relative to it. This functionality is in particular useful for crosshatches.

If the control box at the end of the ruler is pressed onto the interaction surface, the device is switched into the red control mode by a microswitch (see Figure 11). Within this mode, the device can be used to control the complete interaction space and thus behaves like a handle for the complete desktop. If the ruler is moved, the back-projected image on the interaction space also moves. By rotating the ruler also the content of the interaction space is rotated. If the slider is moved in the red control modus, the whole image on the back-projected interaction space can be zoomed.

3. Color Pot:
The color pot is another interaction device that has two different operation modes. Within the first mode, it is used as an ink dwell and thus again bases on a well-known metaphor (see Figure 12). The color of the pen can be changed by rotating the color pot until the desired color is visible to the user. The desired color can then be selected and transferred to the pen by just dipping the pen into the pot.
By pressing the color pot onto the interaction space’s surface a first time, another modus is activated. In this modus, any color, which already exists in the image projected on the interaction space, can be picked. This modus is visualized by the fact that the color ring around the color pot disappears, and a crosshair appears inside the pot. This crosshair is used to precisely select the desired color. Pressing the color pot a second time onto the surface, the desired color is picked. This color is now available and visible inside the color pot. It can be selected again by the pen when dipping it into the pot. Pressing the color pot a third time onto the interaction surface, the color pot is in its original modus again.

Figure 12: Selecting a new color by using the color pot

4. Eraser
In order to complete the intuitive interaction, an eraser was realized. The head of the eraser is loosely connected to the main body and can be bended into different directions. In the gap between the head and the main body, there are four micro switches, one at each corner. Each micro switch activates a corresponding IR-LED, which is integrated in the front corner of the eraser’s head. Thus, 1, 2, or 4 LEDs can be activated, depending on how the eraser is pressed onto the interaction space’s surface. The geometry pattern that is generated by the LEDs can be detected by the camera and by this the size of the virtual eraser is determined. If only one LED is visible, the erasing area is very small (for erasing single lines or letters). The erasing size is maximum, if all four IR-LEDs are visible to the camera. Figure 13 shows the very first prototype of the eraser.
Virtual collaborative work
All devices shown in the above can be used simultaneously by multiple users being co-located in the same room. However, an important aspect of working on a digital basis is the transportability of data over the network. Thus, it is obvious to also connect the collaboration partners over a network in order to perform a virtual team session.
For such teamwork it is necessary to also transport the so-called Meta information. This is all information that is not consciously expressed by the team members but is important for a mutual stimulation during the meeting. Meta information is for instance posture, gesture, gaze, or eye contact. We consider the latter to be most important for creativity sessions and thus realized a multi-channel videoconferencing, based on the VIC and RAT components of Access Grid. With that, a system as shown in Figure 14 was realized. The figure shows the interactive workplace together with monitors and cameras during a net-based team session.
Figure 14: Net-based creativity session

The placement of the monitors, their height, and their size allow a full integration of remote partners into the meeting. By placing the camera, the speakers, and the microphone next to the monitor, the typical human behavior during a discussion is supported. The participants face each other, the direction of the image, the sound source, and microphone are identical and thus a natural discussion is possible. Local and remote team members share the same interaction space and have the same interaction capabilities, if two identical tables are interconnected. However, it is also possible to set up collaboration between non-identical devices, like for instance the table and a tablet PC. This allows a very flexible participation and integration of net-based partners, even if they have not the complete set-up of a table.

Summary and Future Work

We introduced a new collaboration environment that allows to perform team meetings in the early stages of product development on a completely digital basis. Combining tangible user interfaces with single display groupware, we realized a system that can be intuitively handled and thus does not impede creativity during a brainstorming session. By integrating a multi-channel videoconferencing system, it is also possible to extend these creativity sessions to net-based team members. The arrangement of local members and virtual representations of the remote partners allow also to transfer important Meta information. All participants share the same workspace on which they can simultaneously interact with several devices, which are already known from daily life. Since the system is scalable, it is also possible to integrate other interaction spaces, like for instance a tablet PC.

Future work will focus on the evaluation and improvement of the system. A main factor will be the comparison of this new digital working method with traditional means of working. For this, a second installation will be realized and virtual team meetings will be compared in efficiency with meetings requiring personal presence. Since the introduced system is only one part of a so-called “Virtual Project Room”, additional components and systems will be realized, like for instance also vertical
workspaces with gaze awareness, a planning and redlining system, etc. An interconnection of all systems will extend the capabilities of the virtual project room from the early design stages also to other stages of the product development process.

References


[22] Mimio; http://www.mimio.com/
