A Literature Survey of Single Display Groupware Interaction for Large Screen Collaboration

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ABSTRACT

This paper presents a survey of research papers, within the research field of single display groupware, dealing with utilization of large screens for collaboration. The papers have been selected from three different digital libraries. An explorative study of these papers has been performed to decide upon a meaningful way of categorizing research within the field, and unite the lessons learned by previous contributors to the field. The contribution is an overview of the research field and in particular a resource for a practitioner within the field to consult when designing such systems.

The overview is provided through a matrix classifying 30 papers dealing with an actual system in accordance with the input devices applied and the system level interface. In addition to this a listing of design challenges associated with employing large screens for collaboration is presented along with references to papers providing proposed solutions.

We conclude that there is a tendency towards utilizing touch screens in pervasive systems and remote input devices in ubiquitous systems while there is a lack of research regarding the combination of remote and direct input devices for ubiquitous systems. Furthermore we conclude that the main design challenges researchers report relates to issues of concurrent interaction with the system.

1. INTRODUCTION

A black- or whiteboard is a useful artifact when people collaborate in order to coordinate their activities. Such a board provides a shared overview of information and activities. As it becomes possible to create computer screens which are equivalent in size to these boards it becomes feasible to develop systems to support collaboration through a large screen. This area of interest has already begun to be explored by researchers and is commonly known as Single Display Groupware (SDG). The SDG research field is a sub domain of Computer Supported Collaborative Work (CSCW) which includes systems supporting collaboration in general.

A definition of CSCW which many researchers within the field have adopted was given by Schmidt and Bannon in 1989. [27]

> *"CSCW should be conceived as an endeavour to understand the nature and characteristics of cooperative work with the objective of designing adequate computer-based technologies."*

Traditionally collaborative interfaces are decomposed into two critical dimensions [1] within CSCW as presented in Table 1 which maps the systems in relation to time and place based on the article by Ellis, Gibbs and Rein [6]. However a collaborative system can be utilized in ways which combine more than one of these dimensions.

	Same Time	Different Time
Same Place	Synchronous local (Face to face)	Asynchronous local
Different Place	Synchronous distributed	Asynchronous distributed

Table 1: Collaborative interfaces

The part of the SDG research field which we are interested in, can for most systems presented within the field be categorized as synchronous local according to Table 1; at the same time, at the same place. But as described previously some systems do incorporate other dimensions such as cooperative work at different time in the same place. [38]

Within the field of CSCW some researchers investigate how to support collaboration between distributed users. The goal of SDG research is investigating the best way to support user collaboration while using a system with a single output display. These systems may accept input from more than one user simultaneously and allow users to directly manipulate documents on the common display. Visualizing the behavior of each user enhances the awareness of what is being performed and thereby increases the efficiency of the group collaborating. [30, 34]

The goal of this paper is, through an explorative study of research papers, to create a meaningful categorization of previous research and collate important design experiences, which researchers have reported.

The paper is composed by an introductory presentation of related work and how our contribution differs. This is followed by an explanation of the method we used for selecting papers to be included in an overview of SDG systems utilizing large screens. The overview is presented through a matrix, which is described in detail later. Next we present a number of design challenges regarding utilization of large screen systems which where identified through our survey. In conclusion we present the matrix including 30 systems, and discuss the distribution of these followed by a table of design challenges and references to papers proposing possible solutions.

2. RELATED WORK

Generally speaking there are two distinct reasons to perform a survey of literature. The first reason can be described as a desire to unfold the complexity of a field of research with regard to what is being done, any areas where the research is not fully developed or simply to ascertain the level of "understanding". Another common reason is to extract the current design guidelines as presented in the literature, both with regard to the design guidelines themselves and any lessons learned from their application. Both of these premises are adopted within this paper.

In 1990 Wynekoop and Conger [40] presented a review of Computer aided software engineering research methods, which outlines the strengths and weaknesses of these methods. This was done by first presenting each method with its strengths and weaknesses individually and then finally presenting a categorization hereof, where all were presented in relation to each other. The categorization mapped the research articles at that time in relation to the different methods which provided a clear overview of which areas researchers focused on.

In 2003 Kjeldskov and Graham [15] presented a article which re-evaluated the terms used by Wynekoop and Conger in the context of mobile HCI. They presented a more specialized set of classification terms and presented a matrix which outlined the research within the field of mobile HCI. Again this provided a clear overview of which methods and areas within HCI researchers focused on and which areas got little attention.

We have distinguished ourselves from the above mentioned literature surveys by adopting an explorative approach in order to identify a meaningful way of categorization, and not being predetermined to focus on e.g. research methods.

3. METHOD

In order to perform a survey of the current literature on SDG systems we have gathered papers from a number of journals and conferences. The purpose was to find papers for inclusion in an categorization as presented by a matrix presented later on. This section details the six step selection and categorization process which we performed to find and ultimately categorize the papers.

The first step was to select the digital libraries which might contain relevant papers. Criteria of choosing which libraries were that they should contain papers with focus on HCI, ubiquitous computing as well as CSCW. We chose the following three digital libraries as we had online access to all of these; ACM digital library, Springer Link and Elsevier.

The second step in the selection process was to search for papers within the libraries. We chose "Collaboration" as a main search keyword and performed searches combining this word with "Large screen", "Large display" and "Wall sized display" respectively. The three digital libraries were divided among the three researchers for individually searching and yielded a total of approximately 900 search results.

The third step was reading abstracts of all the papers to determine if they dealt with collaboration on a large screen, as the search criteria was solely that the papers should contain both the search phrases. If reading this didn't suffice to decide our criterion continued reading was required. Reading the abstracts also revealed that many papers were found more than once. After reading abstracts and removing systems which did not match our criteria we were left with approximately 130 papers.

Fourth step was a thorough reading of the 130 papers to decide upon a meaningful way of categorizing them. Actual categorization was first done in the seventh step. We decided to use a technologically point of view, more specifically by type of input device utilized in the concerning system as well as the embeddedness and mobility of the system, which we refer to as the system level interface. These two factors constitute the axes of a matrix used to create an overview, and are described in detail in section 4.

In the fifth step we decided to employ a procedure which in retrospect appeared inappropriate. We decided that each researcher should grade each paper on a ten scale relevance rating. Relevance was not formalized but relied solely on undefined content concerning collaboration and utilization of large screens. The idea was to select papers with an average rating of five or above to be included in a classification. This procedure had some shortcomings with regard to the scientific validity and the possibility of replicating our process. After realizing this we decided to redo the fifth step in a more formalized matter.

In the reapplication of the fifth step we employed four requirements for inclusion in the classification. The paper must concern an actual system, it must contain a description of how the system is used, the interface of the system must be classified as synchronous local according to Table 1, and qualifying as a SDG system and the fourth requirement was that the paper should concern some collaborative aspect. Each paper received one point for each requirement met by the paper.

The sixth step was a final selection based on the rating of the papers. Here the papers with a rating of 4, meaning they met all four requirements, were selected for inclusion which resulted in a final collection of 30 papers. Then we categorized the papers which made it through the final selection in a matrix. In order to categorize these papers in the matrix each researcher made an individual classification. We then met and consolidated the classifications which we had made. The papers which were classified differently by the authors were discussed until a common classification could be agreed on. There were 6 papers of the 30 selected papers which were discussed.

4. FIELD OVERVIEW

We have categorized the papers as presented in Table 2, which expands between two different axes. The horizontal axis is the system level interface which is divided between four levels of mobility and embeddedness. The vertical axis is the input devices applied to the system, which is divided into the two distinct top level categories, remote input and direct input. From this we present an overview of which combinations of input device and system level interface researchers have favored. The two axes will be elaborated upon in the following sections. The numbers in the matrix represent a particular system and correspond to the reference list at the end of the paper. A system can appear in several different categories on the horizontal axis.

		System Level interface			
		Pervasive	Ubiquitous	Traditional	Mobile
Remote	PDA	2, 13	38, 35, 8	20	
	Mobile-phone		38, 23		
Direct	Mouse	5, 30, 34		4	
	Pen	7, 28			
	Touch	16, 14, 22, 9, 25, 29, 10, 31, 39, 18, 37, 26	38		
	Speech	16, 25, 18			
	Computer[1]	12, 22, 11	38, 8	33, 24	
	Other	22, 21, 25, 13	35		
Unique systems		22	4	4	0

Table 2: Matrix of SDG systems

4.1 SYSTEM LEVEL INTERFACE

As we wish to present a clarification of the literature which investigates how to utilize large screens, we have chosen to outline them according to the type of system in which they are integrated. During our literature study we have noticed that some of the systems which we have examined utilize some form of hybrid between the large screen and some remote device trough which users provide input to the system. This has inspired us to categorize the systems by how they are integrated into the surroundings and the patterns of use associated with the system. We call this the system level interface, represented by the horizontal axis, and refer to the level of embeddedness and mobility, which will be explained in the following.

When concepts such as mobility and embedded interfaces are introduced the traditional paradigms of interaction are challenged to accommodate these changes. As a consequence of those changes, new terms have arisen, such as pervasive computing, mobile computing and ubiquitous computing. As described by Lyytinen et al [17] it is possible to categorize these forms of computing by the level of mobility and the level of embeddedness.

The model depicted in figure 1 details this. Pervasive and ubiquitous computing are often used as interchangeable terms, we have chosen to adopt the distinction defined by Lyytinen et al [17] where pervasive computing is categorized as having a lower level of mobility inherent in the concept it embodies.

In order to distinguish between pervasive and ubiquitous systems we have defined pervasive systems as systems where you have to be in a specific place in order to interact as opposed to ubiquitous systems which provide you with methods to interact while on the move.

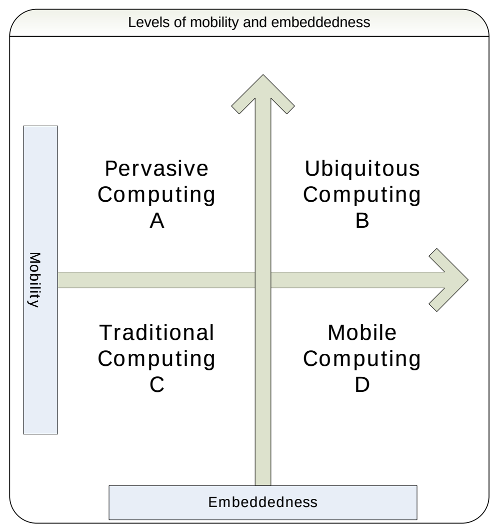


Figure 1: Embedded vs. Mobility

4.2 INPUT DEVICE

The vertical axis of the matrix is denoted input devices. An input device is the method or technology which provides input to a system, such as a PDA, a mouse or a touch screen. These input devices have been divided into two different categories, Remote input and direct input. Remote input consists of devices which provide the user with an alternate way of viewing the object or document being manipulated. Direct input consists of devices were the only means of feedback is the large screen. There is a category denoted "other" which consists of experimental types of input devices which we could not place in any other category. An example of these would be gesture tracking [25]

As we have investigated the many research projects which explore collaboration on large screens we have found that many of them discuss the type of input which will be utilized. There are many examples of systems where the researchers try to develop

[1] The category Computer is a normal desktop setting with a keyboard and a mouse

new input devices and systems which utilize a hybrid of existing methods. Therefore we find it relevant to discuss the challenges for designing systems with large screens.

5. DESIGN CHALLENGES

As we mentioned initially, this paper presents an overview of design challenges when employing large screens for collaborative systems. We have done this by first looking at the benefits and drawbacks which researchers within the field have stated. Secondly we will discuss the traditional paradigm for designing system interaction opposed by the changed setting which large screens introduce.

5.1 COLLABORATION

Researchers have been experimenting with collaboration on large screens for the past two decades. During this period the research community has witnessed many qualified suggestions to how this can be achieved. In order to understand how researchers believe these system will be used we will first outline their arguments for introducing collaborative workspaces on a single display. We will state both the benefits of the technology which researchers have foreseen but also the limitations which they fear this technology may introduce. This should provide us with an overview of the precautions and visions which this new technology may precipitate.

5.2 Information storage

In 1987 Stefik et al. published an article about their work with a SDG system. [33] they state that when collaborating many people uses a chalkboard or a similar tool as help to provide shared and focused memory, a flexible placement of text. But the chalkboard also has several limitations. It has limited space, inflexibility when rearranging text, unreliable data storage as text may be removed by the next person using the chalkboard. So they argue that most of these problems can be relieved easily with the use of computers, as they can both capture the data presented on the screen as well as provide flexible text manipulation. Information can be stored until the next meeting where it can be retrieved and at the same time preserving the state it was stored in. Stefik et al. are very specific about what the benefits of introducing this technology are. They state that it provides a way for users to manipulate their work with as little hindrance as possible.

Izadi et al. [12] agree with this as they have found that many systems utilizing large screens often limits sharing documents between people to transferring between personal devices which can be awkward when there are many people involved. They state that SDG systems can provide ways for users to share documents with little hindrance.

5.3 Collocated Collaboration

Shoemaker and Inkpen [30] state that the benefit of SDG systems is that the combination of the systems and the physical proximity of the users allow a more natural and efficient communication between users collaborating when compared with collaboration on separate displays or remote workstations. It is interesting that we have only found one article which explicitly states this as the primary benefit of these systems.

In their article [34] Steward et al. support what Shoemaker and Inkpen have stated explicitly. Steward et al. have produced a list of positive and negative effects which these new systems may bring with them. In support of Shoemaker and Inkpen they state that allowing multiple input devices to the same display will enable work to be done in parallel. This will make collaboration more efficient and enjoyable.

Steward et al. also state that they se a potential for this new technology to strengthen the communication skills of the users. Strong willed users will not be able to monopolize tasks by controlling the input device. Users will have to resolve conflicts more through communication.

5.4 Concurrent Manipulation

Izadi et al. [12] state that when large surfaces are used in many places they very often restrict the use to only one person and thereby limit the sharing potential of the surface. It is seen as a hindrance that most systems utilizing a large display only allows one user to manipulate the content. They believe that one of the strength of SDG systems is their ability to allow more users to manipulate the display simultaneously, though this may introduce other problems.

Lopez-Gulliver et al. have created the system SenseWeb [16] which is an attempt to support collaborative discussion and sharing experiences amongst users. They also state that the benefits of a SDG system are that these systems can accept multiple inputs from users in a natural way which allows users to manipulate any document at any time. This eliminates the normal turn taking for the input device and permits a more natural turn taking according to the flow of the conversation.

This is also supported by Steward et al. who state that large screens may enable new types of interaction which may require several users to collaborate and it may reduce or even eliminate the conflicts which emerge when multiple users attempt to interact with the same application

From this we find that the researchers agree with the benefit stated by Shoemaker and Inkpen. That if the system supports input from more users concurrently this allows the users to benefit from more natural collaboration and turn taking.

5.5 Action overlaps

Izadi et al. [12] and Sugimoto et al. [35] state that a common problem for groupware systems which support concurrent input is that one user's actions overlaps another user's action and thereby they interfere with the work being performed by the other user.

This problem has appeared with the introduction of this new technology and there has not been much research into how this problem might be accommodated by systems. Most of the systems we have reviewed rely on social protocols to adapt and thereby handle this problem should it occur. Social protocol would have to adapt in some way in order to accommodate the changes which these systems apply to work procedures.

This is a problem which Steward et al. [34] are also concerned about:

> *"New conflicts and frustrations may arise between users when they attempt simultaneous incompatible actions."*

Morris et al. have been investigating what can be done to aid collaboration when social protocols fail. In the paper [19] Morris et al. take a look at how collaboration can be supported in order to avoid conflicts. They are interested in discovering how an SDG system can support collaboration as an alternative to relying on social protocol.

Morris et al. state a number of new challenges that are introduced when working with SDG systems. First they state the ability to simultaneously access a shared display can create several types of conflicts. Changing settings which affect other users, reaching into another user's space or manipulating another user's documents are just a few examples.

They hypothesize that when the size of a group grows the social negotiation become even more challenging since it becomes more difficult to maintain awareness of others work.

Again they describe the main problem as being that of the actions of users cause overlaps and interfering with other users. It seems that many researchers are aware that introducing this technology can create complications for the collaboration when you allow multiple users to manipulate the information on the screen.

Steward et al. also hypothesize that one of the negative effects these large screens may produce are that users may collaborate less because they have the opportunity to work in parallel and therefore become focused on completing their own tasks.

This is interesting because it is supported by the findings of Sugimoto et al. who found that the test subject in their research project began to develop ideas on their own and first presented them to the group when they had developed the idea fully. [31]

5.6 Less individualism

Sugimoto et al. have created Caretta [35], a SDG system which integrates personal and shared spaces. They state that many SDG systems have two problems:

- Recognizing own actions
- Supporting personal work

When a group of users simultaneously use a system that accepts multiple inputs but has a single output such as a display, it is often difficult for individual users to recognize the results of their own operations because all the results are visible to all the users

Several studies have shown that supporting individual activities is important - but there is a tradeoff between the two. In most visible systems of SDG or with augmented reality, a visible workspace is shared among all the users, and therefore it is difficult to support fully each user in his or her personal work within the collaborative area.

Another critical issue is that users have no way of concealing their actions from the other users because they have a shared view.

All these problems concern the user's individuality as Sugimoto et al. state that a limitation of SDG systems is that they lack a method for visually distinguishing the actions of one user from another user and they provide no way for users to work in private, in relation to this problem they state that a SDG system neither provides any way for a user to conceal their actions from the other users, nor can they always observe the actions of the other users.

5.7 A NEW PARADIGM

Based on the statements from the previous section we find it interesting to look at the principles for interaction design which are currently being used. As stated by many of the researchers we have presented the interaction with a SDG system may be quite different compared to interaction with traditional systems. There are new ways of interaction which must be supported and new possibilities for interaction which may be explored.

Table 3 is an overview of what characterizes the traditionally desktop use paradigm compared to the characteristics of a new large display use paradigm.

"Desktop use" paradigm	"Large display use" paradigm
Seated facing centre of screen	Standing or moving around facing a portion of the display
Screen size within a range of 15' to 23'	Beyond 23' and as big as wall size
Mouse and keyboard as input devices	Multiple possibilities for input both as remote control and direct manipulation
Single user involvement	Several users collaborating

Table 3 Differences between desktop and large screen use

When designing systems involving large screens, one must take into account that the traditional characteristics have changed and therefore a different paradigm of use evolves. Firstly screen size is obviously beyond 23' - wall-sized at that [9]. Secondly a user interacting with such a display is not seated in front of the display at a limited range but may do so from different distances, with changing visual angels hence not having a complete view of screen content at all times. Thirdly alternative ways of input, such as touch sensitive screens, laser pointers or remote control through mobile phones or PDA's are being tested and experimented with. Lastly the context of use within large screen systems could involve several people collaborating within a common physical space sharing the same display and interacting with it concurrently. [12, 16, 19, 34]

As a result of these differences compared to desktop use, novel styles of interaction may be needed or known ones refined to suit the new paradigm best possible.

Prior research on using large screens in various computer applications has revealed the following important aspects of large screen use.

5.7.1 Display configurations

When dealing with large screen displays it is tempting to think in terms of normal displays just quantitatively bigger. But besides the larger scale there are a few more important aspects of large screen configuration to take into account. Swaminathan and Sato propose three distinct configurations of large displays pointing out advantages and disadvantages of each [36]

- **Distant-contiguous:**
- **Desktop-contiguous:**
- **Non-contiguous:**

Distant-contiguous consists of large contiguous display placed at a distance occupying a visual angle of 20 to 40 degrees. Advantages are that the user can view entire display without rotating neck, and it provides a large drawing surface.

Disadvantages are excessive eye strain for doing sustained and detailed work.

The desktop-contiguous configuration is a large display with the user seated within standard reading distance as in a normal desktop setting. It is advantageous for displaying large amount of interrelated information. The disadvantage of this configuration is that the user will not have a complete view of the display.

Non-contiguous is multiple display surfaces possibly at distinct distance from the user. Among non-contiguous displays Swaminathan and Sato distinguish between continuous and separated displays. Continuous display is multiple smaller displays treated as a single conceptual canvas making movement of objects within screens possible. Advantages are the flexibility of being able to configure the single displays as needed.

5.7.2 Navigation and control

When using a computer in a desktop setting the mouse is used as a primary input device. Besides the command line interaction method, the mouse plays a key role in all other forms. The mouse is characterized by the following features. [36]

- It traverses a continuous trajectory between any two points on the display
- It provides a linear (and therefore intuitive) mapping between a user's hand movement and the pointer movement on the display
- The entire width of a SVGA display can be covered – with reasonable accuracy and control – by a single hand movement while resting the wrist on the desktop.

When interaction with large scale displays a mouse is not necessarily available or necessarily suitable for the task. As display size extends it becomes harder, at some point impossible, to traverse the entire area of display with a single hand movement. Secondly accuracy and control is compromised. Instead Swaminathan and Sato [36] present alternative categories of interaction with large screen displays:

- **Direct manipulation**
- **Nonlinear mapping with sticky controls**
- **Dollhouse metaphor**

Direct manipulation is achieved through touch sensitive displays and laser pointing. An advantage is that the users do not have to move a cursor among positions on the display in order to select objects

The idea behind nonlinear mapping is to have a traditional cursor controlled by a mouse. Instead of a linear mapping between hand movement and cursor movement the cursor will speed up in empty areas of the screen and slow down when approaching an area of possible interest, making them "sticky". This solution is suitable for applications where only a few distinct objects reside on the display and pointer accuracy is not critical.

Dollhouse metaphor is an area of the display is reserved for the "dollhouse" which is a downscaled representation of the whole display. Object manipulation and pointer movement is then carried inside the dollhouse and the main display updated accordingly to user actions

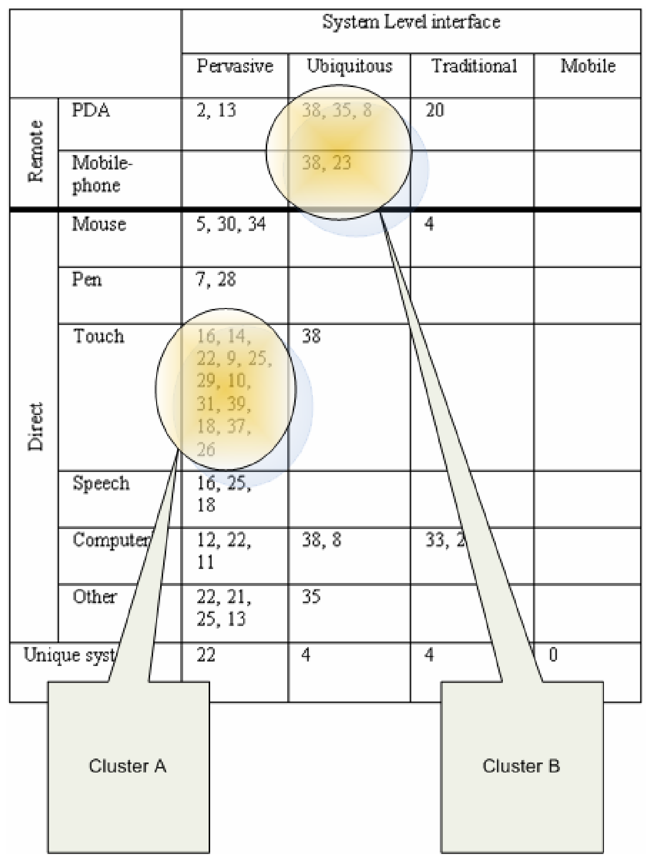
So the new paradigm for interaction design must embody a way of handling the new dimension surrounding the large screen interaction. Users are not sitting directly in front of the screen they may move around and interact at different distances, with different means of providing input. Also this new design paradigm must discover ways to handle input from more than one user performing concurrent actions and handle their actions when they conflict. Comparing the use of mouse as primary input device in classical desktop setting with the input devices we have presented in the matrix in Figure 2 we find that the mouse is far less considered as a mean for providing input for large screen collaboration. This indicates that researchers within the field are exploring alternate means of input.

6. RESULTS

This section presents the results of our literature survey. It begins with an overview presented by the matrix as described in section 4, and after a discussion of its content a collection of design challenges along with references to papers and the corresponding solutions is presented.

6.1 Research Focus

The matrix we present visualizes the characteristics of large screen display systems in regard to our two axes. A system with low mobility and high embeddedness utilizing a PDA would be placed in the pervasive category and this is an example of a possible configuration of a system. Systems which utilize the same input device are placed together in their particular box on the vertical axis within the matrix. Systems which utilize more than one input device therefore appear in more than one category.



		System Level interface			
		Pervasive	Ubiquitous	Traditional	Mobile
Remote	PDA	2, 13	38, 35, 8	20	
	Mobile-phone		38, 23		
Direct	Mouse	5, 30, 34		4	
	Pen	7, 28			
	Touch	16, 14, 22, 9, 25, 29, 10, 31, 39, 18, 37, 26	38		
	Speech	16, 25, 18			
	Computer	12, 22, 11	38, 8	33, 2	
	Other	22, 21, 25, 13	35		
Unique syst		22	4	4	0

Figure 2 - Clustered matrix

The matrix details to what extent different categories of systems have been researched, indicating which categories that are currently not as thoroughly researched.

The matrix in Figure 2 reveals that most of the papers concerns research on pervasive systems and of these more than half has utilized a touch screen either alone or in conjunction with another means of providing input as illustrated in cluster A in Figure 2 - Clustered matrix. This as a natural consequence as research on SDG is conducted to support co-located collaboration. Some of the papers has dealt with collaboration in a meeting setting [29], [43] where it is typical to use a blackboard or whiteboard and it therefore seem natural to replace these with touch sensitive large screens. This allows people to continue collaborating as normal while adding the functionality of the computer.

We find it interesting to discover that many researchers investigate alternate ways to allow the users to provide the system with input, either as a supplement to the touch screen or as an alternative all together. We see this as an indication that a normal desktop input method may not be a sufficient means of interaction when users are collaborating in front of a SDG device.

We see that there is almost no research on utilizing remote input devices for pervasive systems. This may be because these systems have a tendency to transform into ubiquitous type of system or merely because it does not seem as a natural way to provide input to a system of this kind, we see it as an interesting idea to examine the effect of utilizing a mobile device as a remote control for a pervasive system. According to our definition of pervasive systems this would require that the mobile device could not manipulate the system without having access to the stationary screen. This may be an interesting research topic to explore the possibility to provide people with a remote control as means of conducting simultaneous topic searches on the mobile device while someone else is using the large screen in a different manner or the mobile device might offer a level of privacy with regard to the actions of the user.

The picture becomes quite the opposite when we view the ubiquitous column. Here it appears that most research has been done on how to utilize remote devices to provide input and almost no research on most of the direct devices see cluster B in Figure 2 - Clustered matrix. The research on remote devices to provide input is not surprising as this is fundamentally what affords the system with a ubiquitous nature, the ability to manipulate the system while moving. But the limited research utilizing the variety of direct input devices in ubiquitous systems comes somewhat as a surprise. We find it interesting that the two systems beyond those produced by Trevor et al [38] which utilize a direct input device do not utilize a touch screen but a normal keyboard and mouse and manual manipulation of the objects on the board, as in the Caretta [35] system. It may be interesting to conduct further research into the combination of remote and direct input devices for ubiquitous systems and especially the utilization of touch screens which have received such extensive attention within the pervasive category.

The matrix shows that no papers did concern a system that could be classified as mobile. We believe this is very natural as collaboration on a SDG system very often evolves around a large stationary display and this provides a hindrance as to the mobility of the system.

6.2 Design challenges

Through our study of the papers we have found five design challenges which are introduced when employing large screens for collaboration. These are listed in Table 4, along with references to papers dealing with the particular challenge, and if available a reference to papers providing a solution proposal for the challenge. The phases in the table are references to subsections in section 5.

Design challenge	Describing paper	Solution proposal
Action overlaps	30, 34, 40	34, 30
Less individualism	37	29, 36, 8
Display configurations	11	7, 15, 18, 34
Navigation	31	2, 15
Input devices	31	11, 40

Table 4 - Design challenges

Action overlaps refers to the conflicting actions which may occur when users are allowed to perform concurrent actions. Many researchers have stated that one of the benefits of introducing large screens to collaborative work is that it allows a more efficient collaboration as well as a degree of concurrent manipulation of documents and objects. In general researchers state that large screens will allow users to collaborate more naturally according to the flow of the dialog. But they also worry that allowing concurrent actions may be the cause of conflicts and that current social protocols may not be able to handle the new conflicts which may arise. We find this to be one of the greatest design challenges which these new systems introduce.

Some researchers have also stated that the introduction of large screens results in less individualism for the actions of each user. By making them collaborate on a single display through multiple inputs the actions of one user becomes less visible and this also removes the privacy of each user.

We have also argued that the current way of designing interfaces may be insufficient in regard to designing for large collaborative screens and a shift in the design paradigm may be required. This requires that the design of such systems is aimed at supporting new display configurations and therefore it is also necessary to consider how users are going to navigate the systems as their behavior in front of the screens will be very different from that of the traditional setting.

One of the reasons why researchers experiment with new types of input devices may be that when the design paradigms are changed it is also necessary to rethink how users provide input to the system as this is a very central part of the interface.

We see that many researchers wish to provide the users with a more natural way to provide the system with input, while at the same time allowing them to perform concurrent actions or allow a normal turn taking without conflicts. Most strive to support collaboration so it becomes as natural as possible. We find that this is another expression of a change to the design paradigm. They strive to support a natural collaboration and therefore try to model collaboration in the real world between people sitting by tables or standing in front of a blackboard. These systems must support the spontaneous evolution of ideas which occurs when people collaborate and it is natural for researchers within a new field of research to begin exploration of the field by mapping the real world.

7. CONCLUSION

We have presented an overview which categorizes collaborative systems utilizing single display groupware with large screens in the context of an input device axis and a system level interface axis. From this categorization we have learned that two thirds of the research presented within the matrix on single display groupware utilizing large screens has been conducted on pervasive systems. We have not found any research on mobile computing in the context of this area of research. We have also found five design challenges which arise with the introduction of large computer screens to collaborative settings.

A limitation of this paper is that we have only searched three libraries for relevant papers and it is possible that we have missed a number of papers which may also have been pertinent to this review. It is our opinion that the papers we have found constitute a representative of the available literature on the three libraries we have searched according to the criteria we have stated.

Based on the distribution of systems in matrix we believe that it could be interesting to investigate how a collaborative system could become mobile beyond a remote control usage. Is it possible to allow the user access to a large display anywhere without the need to visit certain rooms or spaces where these screens are placed? We have found two areas which we find interesting to explore in our future research. How to utilize a combination of direct input methods and remote input methods to provide a collaborative ubiquitous system and how to design a mobile single display groupware system interacting large screens.

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