Collaborative Interaction through Spatially Aware Moving Displays

Anderson Maciel
Universidade de Caxias do Sul
Rod RS 122, km 69 sn
91501-970 Caxias do Sul, Brazil
+55 54 3289.9009
amaciel5@ucs.br

Luciana P. Nedel
Instituto de Informática, UFRGS
Caixa Postal 15064
91501-970 Porto Alegre, Brazil
+55 51 3308.7037
nedel@inf.ufrgs.br

Eduardo M. Mesquita
Instituto de Informática, UFRGS
Caixa Postal 15064
91501-970 Porto Alegre, Brazil
+55 51 3308.6168
emmesquita@inf.ufrgs.br

Marcelo H. Mattos
Instituto de Informática, UFRGS
Caixa Postal 15064
91501-970 Porto Alegre, Brazil
+55 51 3308.6168
mhmattos@inf.ufrgs.br

Gustavo M. Machado
Instituto de Informática, UFRGS
Caixa Postal 15064
91501-970 Porto Alegre, Brazil
+55 51 3308.6168
gmmachado@inf.ufrgs.br

Carla M.D.S. Freitas
Instituto de Informática, UFRGS
Caixa Postal 15064
91501-970 Porto Alegre, Brazil
+55 51 3308.6811
carla@inf.ufrgs.br

ABSTRACT

In many real life situations, people work together using each their own computers. In practice, besides personal communication, such situations often involve exchanging documents and other digital objects. Since people are working in a common physical space, it is a natural idea to enlarge the virtual space to a common area where they can exchange objects while taking advantage of the collaborators' physical proximity. In this work we propose a way to allow collaboration through the interaction with objects in a common virtual workspace built on the top of tablet PCs. The concepts of dynamic multiple displays and real world position tracking are implemented exploiting the tablet's embodied resources such as webcam, touch-screen and stylus. Also, a multiplayer game was implemented to show how users can exchange information through intercommunicating tablets. We performed user tests to demonstrate the feasibility of collaborative tasks in such environment, and drawn conslusions regarding the impact of the new paradigm of extended multi-user workspaces.

Categories and Subject Descriptors

I.3.6 [**Computer Graphics**]: Methodology and Techniques—*Interaction techniques*; H.5.2 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Artificial, augmented, and virtual realities*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Input devices and strategies*

Keywords

User interfaces, Interaction metaphors, Tabletop applications, Interactive devices and techniques

1. INTRODUCTION

Today, "many" people depend on both computers and information sharing for professional or personal purposes. Significant, common tasks are maintaining documents and files, following news, communicating with other people for work or friendship, exchanging files in real-time or simply playing games and having fun.

In this scenario, the sense of urgency is often present and many times, the decision making is really depending on real time information and quick access to other people and documents.

Figure 1: Proof-of-concept prototype of an application for file exchange: multiple users can drag and throw files to each other's workspace.

SAC'10 March 22-26, 2010, Sierre, Switzerland.

To help people to be part of this new reality, a large number of devices and tools are already available for a reasonable price. Devices such as laptops, GPS and smartphones as well as tools for allowing internet connection, video conference, file exchange tools, on-line photo albums, and so on are some examples of available facilities.

However, even if the real-time collaboration with people that are geographically spread is easily achieved through the current communication tools, a number of tasks depend on the interaction among people placed in a common physical space. In these situations, the possibility of a direct contact would avoid the need for computer-based tools to facilitate person-to-person communication. But, as most of the information is digital, there is yet a need for tools to assist data exchange during such tasks. So, it is a natural idea to enlarge each device's desktop to a virtual space where the digital objects are placed for exchange and interaction tasks taking advantage of the collaborators' physical proximity.

In this work we present an approach to allow for collaboration through interaction with objects in a common virtual workspace by providing:

- a way to extend the size and resolution of the workspace during a meeting, using public available software and tablet PCs;
- a technique to support the exchange of objects during a collaborative task in a natural and intuitive way, sensible to their spatial position (see Figure 1).

To demonstrate the concepts proposed in the present work, we developed and tested an application based on tablet PCs, making use of their several embodied resources such as a built-in webcam, a touch-screen and a stylus. Tablet PCs have been developed with the aim of replacing conventional laptops and palmtops when their use is unpractical or the applications demand new interaction modalities. They combine mobility, computer power, easy interaction and a reasonably large high resolution screen [6].

Natural interaction in a collaborative environment includes basic virtual reality tasks such as navigation, selection and manipulation. It also requires appropriate visualization of the environment. In the present work we explore the concepts of dynamic multiple displays, real world positioning – similar to GPS, machine communication and other resources of the tablet PCs for interaction.

As a validation of the proposed approach, we developed a game application focused on collaborative tasks with tablets. Each user/player uses his/her own tablet to visualize and navigate within a common virtual space, which has the same scale of their common real workspace. They can interact with the game individually and, when two or more users get closer to each other in the real environment, they can start to collaborate to reach their goals more efficiently. We selected a population of volunteers to perform a set of user experiments with the system, logged some of their actions, and analyzed the results.

2. RELATED WORK

Through sharing data, status and location, people owning powerful portable multimedia devices experience enjoyment, social exchange and friendship. Recent works like, 'Connecto' [2], a phone based status and location sharing application that allows a group to 'tag' areas and have individuals' locations shared automatically on a mobile phone, trigger the fast spread of such emergent practices.

As introduced in the previous section, the arise of tablet PCs brought the power of high-end computer workstations to the mobile world. Tablet PCs also provide an alternative interaction form, in which a stylus is used with a touch-screen. Since their release, many new techniques and applications have been proposed to explore this type of interaction. Most of them aim at pedagogical activities. Pargas [5] proposed a software named *OrganicPad* with the goal of increasing the students interest in organic chemistry classes. Depending on the application, the use of a stylus provide a more natural way of expressing ideas than those provided by traditional keyboards and mice.

In the same line, the lecturing system *Classroom Presenter* [1] enables an active teaching environment. It combines extemporaneous slides and annotations by students and teachers using tablet PCs in the classroom. Although many students have laptops today, very few own a tablet PC. To overcome this limitation, *Ubiquitous Presenter* [9] expands *Classroom Presenter* via common web technologies to support non-tablet audiences and enhance student control. A positive side effect of this is that environments with heterogeneous devices are supported. However, depending on the limitations of the device some actions are not possible.

In another branch of related work, we should refer to those related to position and direction tracking of objects and individuals. Among them, the work proposed by Osawa and Asai [4] aims at automatically controlling a camera for video-conference transmission. Position tracking is achieved using the AR-Toolkit library. Tags are rigidly placed both on the speaker and on the pointer, to define a location of interest for the camera to be placed accordingly. Following the same line of AR-Toolkit use is the work of Fiala [3]. In this work position and orientation are controlled by a camera and tags attached to robots and obstacles. This allows tracking the robots positions to control their action in a delimited space.

Non-surprisingly, other more reliable tracking systems, like Flock of Birds, Viconn and Cyberglove have been avoided most probably because they are expensive, cumbersome or non-mobile. Analogously, GPS cannot be used indoors and lacks of accuracy for a number of applications. Nevertheless, new accurate, non-expensive and widely available devices, such as the Nintendo Wii remote controller [8], could also be used in this context and techniques based on such devices will be pursued in future work.

3. INTERACTING THROUGH MOVING DISPLAYS

As mentioned before, this work proposes a solution to assist in information exchange during a collaborative task between people in a face-to-face meeting. In a conventional meeting, people are seated around a table and the exchange of real objects (or documents) is performed by dragging and dropping them on the table top near the people who are exchanging them. Now, supposing that every person is using their own tablet PCs connected through wi-fi, each person will have two workspaces: the real (e.g., the table) and the virtual one (i.e., the virtual desktop within his/her tablet PC). We propose to consider that each virtual desktop is enlarged (e.g., with the same dimensions of the table) so all the users share the same virtual workspace, and can use, in the virtual workspace, the same metaphor of exchanging documents they use in the real table: virtual documents or objects can be shared and exchanged by dragging and dropping them on the virtual desktop.

In the remaining of this section we present our solution for allowing navigation, selection and manipulation with virtual objects in a collaborative environment in terms of implementation.

The system runs on top of HP Tablet PCs model 2710p. Basically, a graphics interface has been written using OpenGL, and the communication system uses the UDP protocol to exchange messages between the tablet PCs. All tablets host the same application software. They control objects in their portion of the workspace and listen to events in a specific port.

3.1 Visualization

Visualization is provided only on tablet PC screens. The application environment is 2D, and the navigation around the workspace is made by position and orientation tracking (see details in Section 3.2). Any changes of viewpoint are then made by moving the tablet PC in the real world; motion is replicated to the virtual camera of the graphics system. The schema shown in Figure 2 illustrates the setup of our technique. We can observe the table area, the virtual workspace (defined by the dashed line), and the outlines of two different subareas of the common workspace, which two tablet PCs are visualizing. To complete the system setup, there is the tagged platform used for tracking, which is presented at the top of the schema.

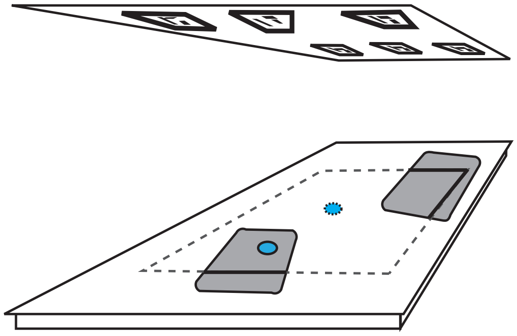

Figure 2: Schema of the system setup. Tablet PCs are on the tabletop while AR-toolkit tags are placed on the flat platform above.

3.2 Navigation

Navigation is accomplished through positioning control based on computer vision. A set of tags is fixed on a flat platform placed above the real workspace (refer again to Figure 2). Real time video containing the tags is acquired by the tablets' built-in webcams, and processed by a control module implemented using the AR-Toolkit library.

AR-Toolkit [1] is a software library created to help building augmented reality applications. It uses computer vision algorithms to track a set of trained tags as they move through space. The inverse can also be done, i.e., using AR-Toolkit to track the position of the viewpoint (camera) in relation to fixed tags. As the tablet PCs are placed on a tabletop, the built-in webcams are always facing upwards, having the tagged platform always in their field of view. This setup allows calculating the camera position in relation to the tags, and consequently the position and orientation of each tablet. The user can then move a tablet in all directions on the tabletop plane, and rotate it, exploring different parts of the workspace.

Finally, this system processes the motion of a tablet in the real world, and causes a proportional motion of the field of view in the virtual workspace, so that the user can search and move objects.

3.3 Selection and manipulation

The tablet PC stylus is directly used for selection and manipulation of objects on the tablet screen (i.e., in the workspace). By touching an object with the stylus, and keeping the contact, a user can stop it, move it around and throw it at will. The velocity on throwing will define the initial velocity of the object, which will decrease along time. The direction of throwing define the trajectory, and when an obstacle is found, e.g. a wall, the object bounces and follow an intuitive rebound trajectory.

4. THE EXPERIMENTAL APPLICATION

In order to validate our proposal, we implemented a game application that can be played in two modes: individual and collaborative modes, which are implemented as single-player and multi-player phases of the game. For sake of simplicity and intuitiveness, the game consists of a virtual, rectangular 2D room without doors or windows. In the room, there is a ball, which the player must throw or drag to a target. As the room is much larger than the display, only part of it fits on the screen at a time. One has to navigate through the virtual room to explore other areas (see Section 3.2). A mini-map is provided at the corner of the screen to aid in orientation, especially for the untrained user. Both the ball and the target are randomly placed at initialization, and replaced just after a goal is scored. The ball can be grabbed and moved with the stylus, and when it is released it maintains the velocity as an impulse that will decrease as it moves - simulating friction - until it stops. The ball also bounces on the room walls. Figure 3 illustrates the game screen.

As mentioned before, the game has two modes: individual (single-player) and collaborative (multi-player) modes. In the multi-player mode or collaborative application, the tablets communicate through a wireless network, and the target becomes the center of one of them in such a way that one of the players moves the target while the other moves the ball. Thus, the task of each player is to help on hitting the target with the ball in the shortest time possible and with the least number of attempts. As one player at a time moves the ball and the other moves the target around, they cooperate to accomplish the common goal, as seen in Figure 4.

5. EXPERIMENTAL EVALUATION

To evaluate the proposed approach, we performed a set of experiments with the game described in Section 4. The experiments were designed as a within-subjects study based

---

[1] http://www.hitl.washington.edu/artoolkit/

Figure 3: Screenshot of the game in single-player mode. Notice the ball, target and mini-map.

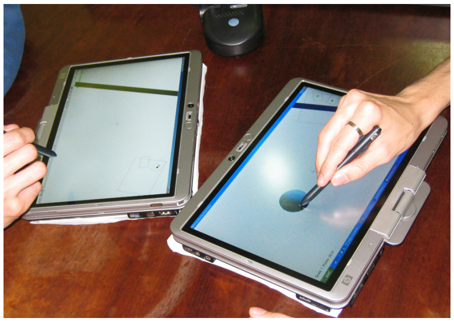

Figure 4: Screenshot of the game in multi-player mode. Interaction between users using two tablet PCs.

on the two hypotheses below:

1. it is faster to hit the target in multi-player mode than in single-player mode (less time to accomplish the task),
2. it is easier to hit the target in multi-player mode than in single-player mode (less number of ball manipulations or clicks on the ball).

The hypotheses were motivated by the assumption that when the user throws the ball and misses the target in individual mode, he/she must navigate to find the new ball position and be able to throw/drag it again, while in collaborative mode, a deviated throwing can be quickly fixed by adjusting the position of the target tablet. So, the collaborative mode should allow the users to finish the tasks within a shorter time and with less manipulations.

In this experiment, the independent variable is the game mode (we can switch between single- or multi-player), and the dependent variables we measure are the number of clicks on the ball, and the time passed until the target is hit. These two measures are automatically recorded in the game log file.

User tests were performed in two steps as described below:

1. *Single-player mode performance test:* the single-player mode is presented to the user, and he/she is asked to score 10 goals by hitting the target with the ball as fast as s/he can and with the least number of *kicks* (clicks on the ball). Goals' times and number of attempts were recorded in the log.

	Single-player		**Multi-player**	
	Time (s)	**Clicks**	**Time (s)**	**Clicks**
Mean	95.25	20.94	89.38	10.88
Std.dev.	37.83	7.4	20.11	1.5
Median	85	20.5	89	10.5

Table 1: Data obtained from the experiment logs.

2. *Multi-player mode performance test:* the multi-player mode is presented to 2 users each time, and they are asked to collaborate and score 10 goals as fast as they can. It should be emphasized that, in this test, when one user kicks the ball the other one can control the target position in such a way that they cooperate on scoring goals. Again, goals' times and number of attempts were recorded in the game log file.

We assumed that until the volunteers had scored the first goal they were still learning how the system operates. So, we analyzed the 9 last successful scored hits from each test.

We selected 16 subjects for the tests.They are undergraduate computer science students, all experienced with games. The volunteers were split into two groups. The first group performed the individual test (1) first and the collaborative test (2) just after. The second group performed the tests in the inverse order, to avoid the order effect that more practice might have in the results.

After the tests, a questionnaire was answered by the subjects. In this questionnaire, they had to assign grades (subjectively) to the game properties. Some answers will help us to improve the technique for future work. Results obtained and statistical analysis are presented in the next section (Section 6).

6. RESULTS

The data we obtained experimentally with both the single-player and multi-player modes is presented in Table 1, along basic statistics.

6.1 Basic statistics

One can observe that the mean time is lower when the subjects performed the collaborative task (mean time for multi player is 89.38, while for single player test is 95.25), which also presented a smaller standard deviation (20.11 for multi player test and 37.83 for single player mode).

Regarding the data about number of ball manipulations, measured through clicks on the ball, we can observe in Table 1 that the users perfomed less ball manipulations in collaborative mode than while playing in individual mode. The mean number of clicks was 10.88 for the multi-player mode (standard deviation = 1.5) while the single-player mode yielded mean number of clicks = 20.94 (standard deviation = 7.4).

We also noticed that tests in collaborative mode resulted a median value of 10.5 clicks on the ball to complete the proposed task, which represents almost one click per target hit since we needed to hit 9 targets to finish the test.

6.2 Verifying the hypotheses

To actually assess the significance of results obtained with the experiments and verify if our hypotheses hold, we used Single-Factor Analysis of Variance (ANOVA) test. Following a within-subjects repeated measurements design we compared the time samples from single-player and multi-player

	Time		**Clicks**	
	Single-player	**Multi-player**	**Single-player**	**Multi-player**
Mean	95.25	89.37	20.94	**10.88**
Std.dev.	37.83	20.11	7.4	**1.5**
P	0.5874		9.12E-06	
F	0.3008		28.4325	

Table 2: ANOVA results for time and efficiency measurements.

tests as well as the number of clicks recorded in the same tests. Table 2 shows the results for both analyses.

Regarding the first hypotheses, i.e. *it is faster to hit the target in multi-player mode than in single-player mode*, we found out that our hypothesis is not proved: there is no difference between the two samples of time measurements. Table 2 shows that the comparison of time measurements samples yielded $F = 0.3008; p = 0.5874$, with $Fcrit = 4.1709$.

The second hypothesis was that in collaborative mode the tasks would be concluded more easily - *it is easier to hit the target in multi-player mode than in single-player.* The ANOVA test showed that this hypothesis holds (Table 2): the difference between samples is highly significant, since we obtained $p = 0.00000912$, $F = 28.432$.

7. DISCUSSION

The game application described in this paper aimed at evaluating the enlarged workspace technique intended to aid the human-human interaction during co-located (face-to-face) collaborative tasks. We had real users in a controlled experiment performing a simple task (throwing a ball towards a target, scoring successful hits) in individual and collaborative modes. The final goal of this work, however, is to provide a new form of interaction to allow users to perform common tasks in a more efficient and/or intuitive way, as well as to create new tasks based on new users' needs.

One applications that can be supported by collaborative interaction through spatially aware moving displays is file exchange. Suppose one arrives in a coffee shop, and has a high performance mobile device such as a palm PC or a tablet PC. Other people on the coffee shop also own similar devices. They can now approach, communicate, exchange information, and work collaboratively using an extended workspace. Better yet if the system takes the real space into account when defining the areas of the workspace a user occupies and share. One specific case of such new form of human communication is to show pictures to friends by dragging them *interdevicely.* The friend then sees the picture arriving on his/her work area, knows where it comes from, and can now interact with it, zoom in and out, copy to her/his own library, pass to another friend, and so on.

We actually extended the game described in Section 4 and used in the experiments, to prove this concept. Figure 1 illustrates the proof-of-concept prototype of such application.

There are other several examples of applications for such extended device-independent work area, as Robertson et al. [7] enumerate. These authors dissociate the concept of display from the concept of monitor device, in such a way that the display is a larger area which a number of devices (monitors, projectors, etc.) can share, allowing the user to interact with. In their work, Robertson et al. evaluate the use of current multiple monitors technology and come up with a number of problems: loosing the cursor, bezel, accessing distal information, window management, task management, configuration. What they missed is the possibility of using mobile position aware displays. By doing so, as we proposed here, most of the problems they analyzed simply vanish.

In a world of ubiquitous computing this is just a start. New advances of display technology point to a situation in which everything will be a potential display, from t-shirts to walls, from table-tops to car bodies. Following the same idea, other media like music, links, profiles can be exchanged based on location of displays, and, for sure, collaborative tasks will arise naturally with the easiness of information exchange.

8. ACKNOWLEDGMENTS

We thank HP for providing the tablet PCs, and the volunteers from the Interactive Visualization Lab for their kind participation in the experiment. This work was supported by grants from CNPq to Anderson Maciel, Carla Freitas and Luciana Nedel.

9. REFERENCES

[1] R. Anderson, R. Anderson, P. Davis, N. Linnell, C. Prince, V. Razmov, and F. Videon. Classroom presenter: Enhancing interactive education with digital ink. *Computer*, 40(9):56–61, 2007.

[2] L. Barkhuus, B. Brown, M. Bell, S. Sherwood, M. Hall, and M. Chalmers. From awareness to repartee: sharing location within social groups. In *CHI '08: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, pages 497–506, New York, NY, USA, 2008. ACM.

[3] M. Fiala. Vision guided control of multiple robots. *Computer and Robot Vision, Canadian Conference*, 0:241–246, 2004.

[4] N. Osawa and K. Asai. Distributed automatic camera control system tracking markers for distance education. In *ITRE*, pages 377–381, 2005.

[5] R. Pargas, M. Cooper, C. Williams, and S. Bryfczynski. Organicpad: A tablet pc based interactivity tool for organic chemistry. *Pen-Based Learning Technologies, International Workshop on*, 0:1–6, 2007.

[6] J. Prey and A. Weaver. Guest editors' introduction: Tablet pc technology–the next generation. *Computer*, 40(9):32–33, Sept. 2007.

[7] G. Robertson, M. Czerwinski, P. Baudisch, B. Meyers, D. Robbins, G. Smith, and D. Tan. The large-display user experience. *IEEE Comput. Graph. Appl.*, 25(4):44–51, 2005.

[8] A. Shirai, E. Geslin, and S. Richir. Wiimedia: motion analysis methods and applications using a consumer video game controller. In *Sandbox '07: Proceedings of the 2007 ACM SIGGRAPH symposium on Video games*, pages 133–140, New York, NY, USA, 2007. ACM.

[9] M. Wilkerson, W. G. Griswold, and B. Simon. Ubiquitous presenter: increasing student access and control in a digital lecturing environment. In *SIGCSE '05: Proceedings of the 36th SIGCSE technical symposium on Computer science education*, pages 116–120, New York, NY, USA, 2005. ACM.