Collaborative Web Search Using Tablet Terminals on a Virtual Tabletop Environment

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Abstract. The *Virtual Tabletop Environment* (VTE) is a tablet-based framework that simulates an interactive tabletop environment suitable for collaborative work. We present a VTE application that supports collaborative Web search. Web views are placed on the virtual tabletop. Users have tablet terminals that provide windows onto the VTE, through which the Web views can be seen and manipulated. Four groups of three users participated in an evaluation of the effectiveness of the system. The results show that discussion and information sharing is more likely compared with collaboration using traditional desktop Web browsers.

Keywords: Collaborative web search · Tablet terminals · Virtual tabletop Environment

1 Introduction

As tablet computer and 'smart-phone' technology advances, these mobile devices become increasingly capable of supporting collaborative work. 'Collaborative Web search' is conducted by multiple users, each using a mobile device to individually search for Web content. Search results are shared among the users as they work towards a common goal.

A user can share their individual search results physically by showing the screen of their mobile device to other users. This is disruptive because it interrupts the search activities of the other users. Results can also be shared electronically by sending search result URLs to other users via an information sharing tool such as Apple's AirDrop. This is also disruptive because the sender must open an information sharing application that is not related to their ongoing search activity.

Useful results can also be lost because sharing is initiated by a single user; if a user does not proactively share a potentially useful result, it will not be seen by the other collaborators. To maximize the benefit of collaborative search, and to minimize the risk of losing useful information, the methods for group communication should encourage instant sharing of individual results within the group.

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Users engaged in collaborative search on a desktop computer can immediately see every search result on a large, shared display. To obtain a similar degree of communication when working with mobile devices we have developed the *Virtual Tabletop Environment* (VTE) [3]. Communication and sharing are encouraged by placing all collaborators' documents on single, shared virtual tabletop surface.

This paper presents an evaluation of a collaborative Web search system, built on the virtual tabletop environment, in which users share information rapidly and with little disruption. Related work is reviewed in Sect. 2. The collaborative Web search system is described in Sect. 3. Section 4 presents our evaluation of the system's effectiveness, compared with users working with traditional Web browsers. Section 5 offers some concluding remarks.

2 Related Work

This section introduces work related to collaborative Web search. We also briefly describe the virtual tabletop environment.

2.1 Collaborative Web Search

Web search has traditionally been a solitary activity, and major Web browsers are designed based on this assumption. Many systems have nevertheless been proposed to support collaborative Web search [5,9] in which members of a group share information while searching the Web to achieve a common goal. Possible scenario of a collaborative Web search task is to plan a travel with friends, decide a product of furniture to purchase with family members and find related research works with laboratory colleagues.

Examples of systems supporting collaborative Web search include GroupWeb [2] which is a Web browser allowing group members to remotely share and navigate Web sites, SearchTogether [6] and Coagmento [10] which target remote users, CoSearch [1] and a collaborative exploratory search system [8] which target co-located users, Maekawa's page partitioning system for hand-held mobile devices [4], and WeSearch [7] which uses a shared tabletop display. Among these, WeSearch is the closest in approach to our system.

WeSearch provides collaborative Web search on a large, shared, tabletop display. Two overhead projectors provide content on a specially-constructed 1.2×1.8 meter touch-sensitive surface. Users collaborate on a search activity simultaneously, standing around the display. Unlike Web search with individual mobile devices, they can easily see what other users are doing during the search process. Users can therefore share not only their results but also the process of Web searching with the other group members.

2.2 Virtual Tabletop Environment

Here we briefly describe the virtual tabletop environment in which a Web search system is built as an application. Detailed design, implementation and analysis of the VTE can be found in a separate article [3].

The VTE provides a shared workspace extended virtually over a normal tabletop, whose content is viewed on the displays of mobile tablet computers. Direct manipulation using gestures on the touch-sensitive tablet screens provides interaction with the shared objects in the virtual workspace.

Figure 1 illustrates how collaborative work is conducted on the VTE. Each tablet acts as a peephole, giving its user a moving window onto the much larger virtual space. When the user slides the tablet across the tabletop, the tablet display scrolls so that the content appears stationary on the tabletop. Synchronization among the tablets ensures that, for a given position on the tabletop, the same content will be displayed on any terminal moved to that position.

Preliminary experiments show that VTE users have good situational awareness and understanding of their working area's location within the entire virtual workspace. Spatial relationships between objects are easily understood. Users employ spoken explanations and physical gestures, such as pointing, to communicate information about object relationships within the workspace efficiently.

Our collaborative Web search application lets users immediately share their individual search results within the large common workspace of a VTE. Being able to see and share information within other users' working areas is the key characteristic that the VTE brings to a tablet-based Web search system.

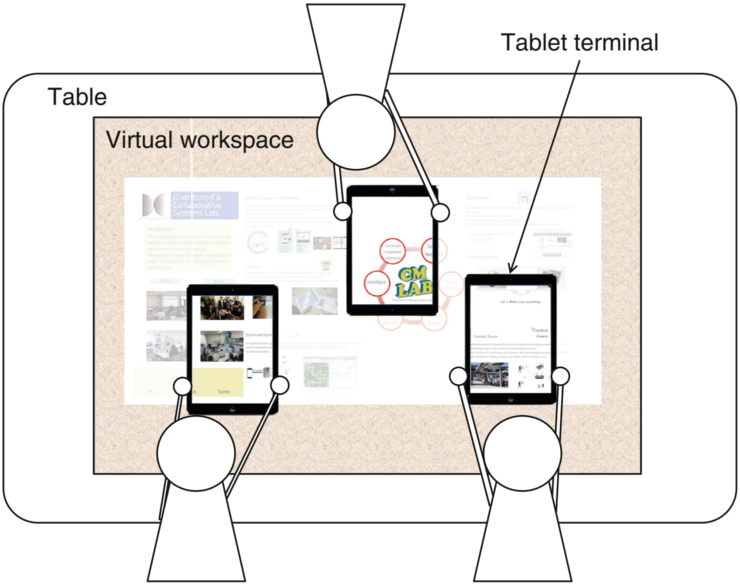

Fig. 1. Virtual tabletop environment

3 The Collaborative Web Search System

This section presents the design and implementation of our collaborative Web search application running on the VTE.

3.1 Functional Design

Shared Workspace. As shown in Fig. 2, users collaborate on a search activity within a large virtual workspace. Each user holds a tablet PC which displays a small portion of the much larger virtual workspace. The portion displayed depends on its physical position of the tablet on the tabletop.

Within the workspace the contents of Web pages are displayed in Web views. Views can be moved around within the workspace. Changes to the number and positions of views in the workspace are synchronized among the tablets; when a new Web view is created on one tablet, the same view is created locally on the other terminals at the same position within the workspace. Contents of Web views are also synchronized; if the content of a Web view changes after following a hyperlink, the view is updated accordingly on the other terminals.

The number of terminals in use need not equal the number of collaborating users. Terminals are not 'owned' by a specific user; users are expected to operate whichever terminal is the most convenient at any given moment.

Users can perform the following actions in the shared workspace:

1. *Change the displayed portion of the workspace*
   Sliding a tablet across the tabletop surface scrolls the displayed portion of the virtual workspace accordingly. (When the system starts up, the initial

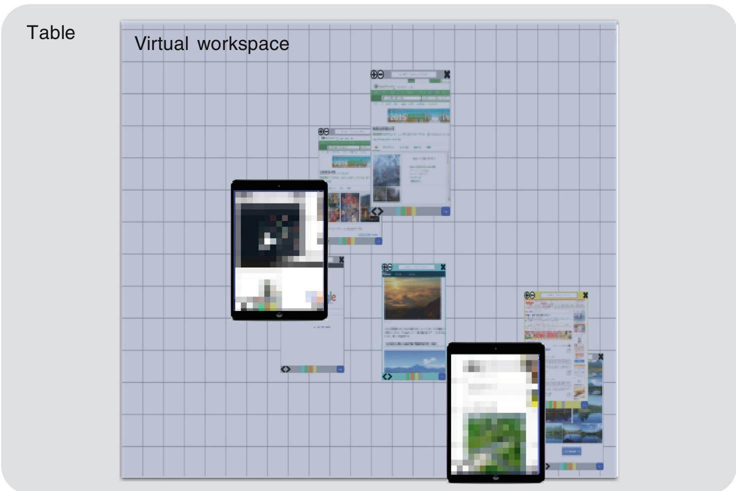

Fig. 2. Shared workspace

physical position of each terminal can be synchronized to one of the four corners of the virtual workspace.)

2. *Display the entire workspace*
Pressing the 'whole view' button lets a user see the entire virtual workspace, as shown in Fig. 3. Seeing the whole workspace gives users situational awareness of where Web views are placed relative to each other, and what Web pages are currently open. Web pages cannot be scrolled in the whole view mode; to see details of the Web page of interest or to interact with it, users need to move the terminal to the location of its Web view while in 'normal view' mode.
3. *Invert the Web view*
Showing a terminal to a user located on the opposite side of the table will present an inverted view of the Web pages' contents. When the 'upside-down view' button is pressed, the contents of all Web views are rotated 180 degrees so that they have the correct orientation for users viewing from the other side of the tabletop.

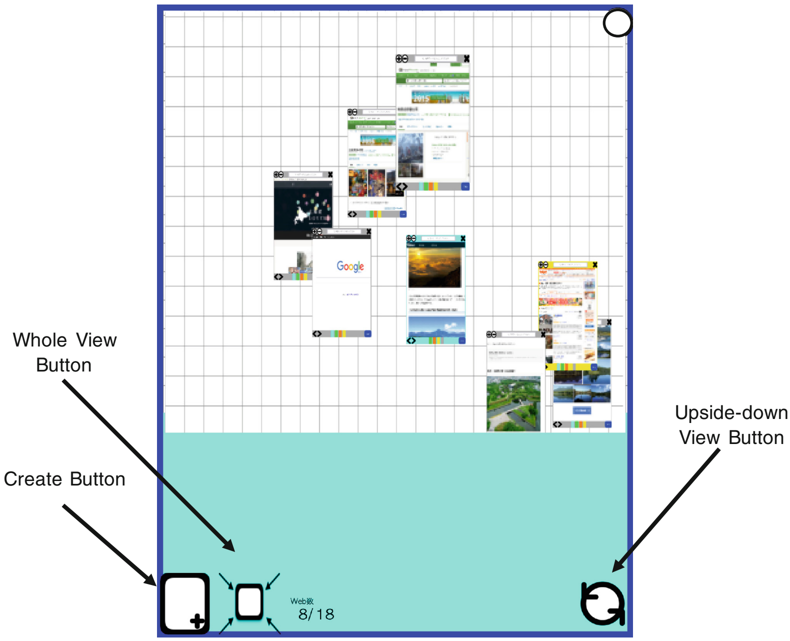

Fig. 3. Whole view

Web Views. Figure 4 shows an example of a Web view. The major functions of Web views are described below.

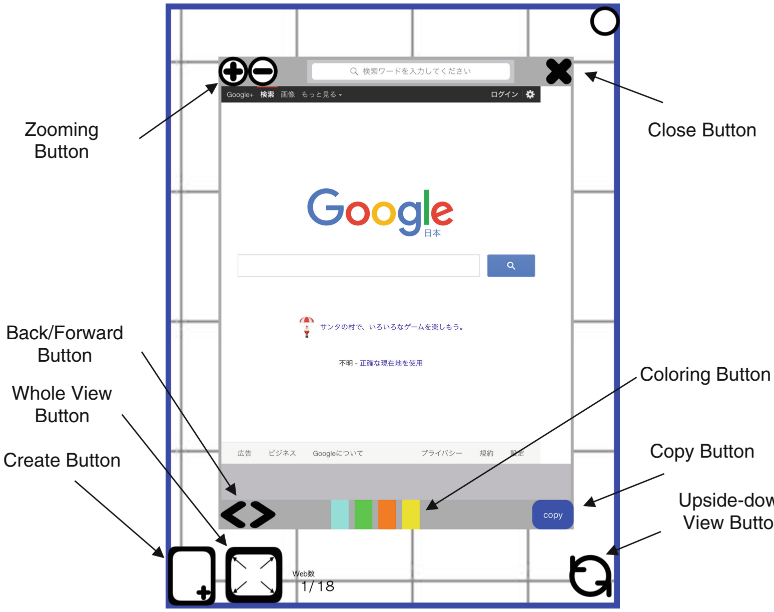

Fig. 4. Web view

1. *Create a Web view*
   Pressing the 'create' button adds a new Web view to the virtual workspace at the currently-displayed location. Web views provide the usual browser functions such as 'back', 'forward', and 'close'.
2. *Move the Web view*
   Tapping and dragging the colored frame of a Web view allows it to be moved within the workspace. Moving the terminal while dragging a Web view causes the Web view to follow the movement of the terminal. Web views can thus be moved easily to any position on the tabletop, which is essential for showing them to, and sharing them with, other users.
3. *Zoom in or out*
   Six levels of zoom are available for Web views, controlled by the 'zoom' buttons. When zoomed out, multiple Web views can be displayed on a single tablet for comparison; when zoomed in, a single Web view can be seen in great detail using several tablets placed next to each other.
4. *Change frame color*
   Every Web view has a frame. The color of the frame can be changed using the 'color' buttons. Frame colors can be used to tag and then easily identify Web views classified according to characteristics such as content, the person who found the Web page, and so on.
5. *Copy the Web view*
   Pressing the 'copy' button creates a new Web view containing the same Web content. Copying is needed to duplicate a view before passing it to a another

user. It is also a way to 'bookmark' a search result by storing its content in a new view before moving on to another Web page within the original view.

3.2 Implementation

We use Apple's iPad with 9.7 in. screen for our implementation. The *Multipeer Connectivity* framework is used to synchronize the virtual workspace among multiple iPads. This framework provides server-less communication over Wi-Fi and Bluetooth.

When a Web view is created or moved, its coordinates are transferred to all the terminals. When the content of a Web view is updated, the corresponding URL is sent to all the terminals. Every terminal's model of the workspace content is therefore synchronized so that users can observe the same workspace contents, with the same spatial relationships, regardless of which terminal they use.

Scrolling the displayed portion of the workspace when a tablet is moved requires a mechanism to measure physical movement on the tabletop surface. In our provisional implementation we use a wireless mouse to measure the movement of each tablet. Figure 5 shows how a mouse is attached to a tablet to detect movement. Movement information is sent to a PC (MacBook) via Bluetooth and forwarded to the tablet via Wi-Fi. The Web view application running on the tablet scrolls the workspace accordingly.

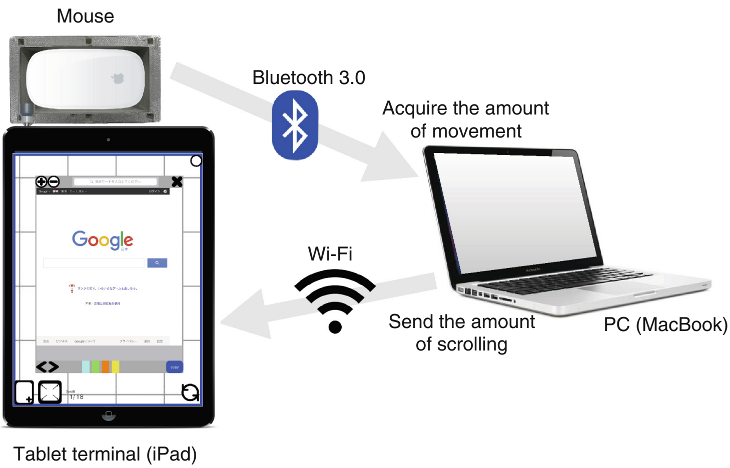

Fig. 5. System structure for scrolling the workspace

Several mice can be connected to a single PC. (Our current implementation allows up to four mice per PC.) A tool running on the PC associates the MAC address of each mouse with the IP address of the physically-corresponding tablet. When movement information is received from a mouse, it is forwarded to the corresponding tablet.

In this provisional implementation, users cannot lift or rotate their tablet because a mouse is attached. We plan to develop a device using a color sensor to detect the absolute position on a colored surface to overcome this limitation.

4 Evaluation

This section presents an experiment to evaluate the effectiveness of multiple-tablet interfaces for virtual tabletop environments by performing collaborative Web search using our prototype VTE system.

4.1 Purpose

The experiment is designed to answer the following two questions:

- How useful is a VTE-based system for collaborative Web search, compared to a traditional Web browser?
- Does changing the number of tablets available to the users affect how they perform the task?

To answer these questions we asked experimental participants to perform a task using three different environments. Table 1 summarizes these environments, each of which is described in detail below.

Table 1. Working environments for the experimental tasks

Task	Working Environment	
Task 1	Safari+AirDrop	N users with N tablets
Task 2	VTE	N users with N tablets
Task 3+1	VTE	N users with $N+1$ tablets
Task 3−1	VTE	N users with $N-1$ tablets

Safari+AirDrop: Participants perform the task using Safari, a standard Web browser on iPad. Search results are shared between users using AirDrop, an information-sharing tool provided on Apple devices.

VTE system with N users and N tablets: Participants perform the task using the VTE-based collaborative Web search system, with the same number of tablets as users. The usefulness of this environment is compared with that of the Safari+AirDrop environment.

VTE system with N users and $N \pm 1$ tablets: Participants use the VTE-based system with either one more tablet than the number of users, or one fewer than the number of users. With $N+1$ tablets we evaluate how a surplus of tablets might be used for the task. With $N-1$ tablets we evaluate how the participants might overcome a small deficit of tablets.

4.2 Experimental Method

Twelve students participated in the experiment. They formed four groups of three participants to perform a collaborative Web search in each of the working environments. In all cases the participants were seated around the same physical tabletop.

The topics of the collaborative search tasks were “find the three best places to visit in western Japan”, “find the three best places to visit in eastern Japan”, and “find the three best places to visit in the world”.

Each group first performed the search task using Safari+AirDrop (Task 1). All groups then performed the same search with the VTE-based system using three tablets (Task 2). The first two groups then performed the search using the VTE-based system using four tablets (Task 3+1), whereas the last two groups performed the search using two tablets (Task 3−1). Before using the VTE-based system, each group was explained how to use the system and given three minutes to become familiar with its user interface. Twenty minutes were allotted for the completion of each task. Figure 6 shows an experiment in progress.

Fig. 6. A scene of the experiment

4.3 Evaluation

Evaluation was based on observation of the participants while they performed the tasks, and analysis of a questionnaire they completed after the task. Tables 2 and 3 list the contents of the questionnaires. Questions shown in Table 2 are designed to evaluate whether participants could share information easily and collaborate effectively. Questions shown in Table 3 are designed to assess the effects of a surplus or deficit of tablets, by asking participants how they used an additional tablet or overcame a shortage of them.

Table 2. Questionnaire comparing Task 1 with Task 2

	Questions	Answer format
Q1	For Task 2, did the chance of seeing Web pages that other users were searching increase?	multiple choice
Q2	(For those who answered "yes" for Q1) Was the sharing of Web information also improved?	multiple choice, and free description
Q3	For Task 2, did placing the Web views on a surface make it easier to compare multiple Web pages?	multiple choice, and free description
Q4	For Task 2, did using "whole view" make it easier to understand the relative positions of Web views?	multiple choice
Q5	(For those who answered "yes" for Q4) How did you use the "whole view" function?	free description
Q6	Comparing Task 1 with Task 2, which did you feel gave more satisfactory search results?	multiple choice, and free description

Table 3. Questionnaire comparing Task 2 with Task 3

	Questions	Answer format
Q7	Compared with Task 2, how did you use the tablets in Task 3?	free description
Q8	Compared with Task 2, was it easy to perform the collaborative search in Task 3?	multiple choice, and free description

4.4 Results

Experimental results concern the two aspects mentioned above: comparing a VTE-based system with the more traditional Safari+AirDrop, and analyzing the effects of increasing or decreasing the number of tablets available to the participants.

VTE compared to Safari+AirDrop

Observations. Participants using Safari+AirDrop first performed Web searches individually using their own tablet. During the task, they showed their tablet directly to others, or exchanged URLs using AirDrop when they found Web pages they wanted to share. Little discussion occurred while performing the individual searches, except in some cases when showing a Web page to another user.

Participants using the VTE-based system first performed Web search individually using their own tablet, as in the case for Safari+AirDrop. When they found a Web page of interest, they shared Web views by moving their terminals across the table or simply by showing their tablet to other users. All of the groups shared Web views of interest by collecting the views together in the center of the workspace. They looked at other users' tablets more frequently than in the case of Safari+AirDrop. They were able to share Web pages rapidly by positioning their terminals over a similar area.

Questionnaires. Table 4 shows the answers to Q1, asking whether the chance of looking at other users' terminals increased. More than half of the participants answered that the chance increased. Participants who answered "yes" to this question also answered Q2, asking whether the sharing of Web pages was improved; the results are shown in Table 5. Typical reasons given in the 'free description' part of the answer were "because we were able to see easily other users' terminals like a shared screen" and "because we were able to look at the other terminals just by moving the terminal a little, and to talk easily".

Table 4. Chances of looking at others' tablets

Greatly decreased	Somewhat decreased	No difference	Somewhat increased	Greatly increased
1	1	2	6	2

Table 5. Experience of sharing Web pages

Not enhanced	Somewhat enhanced	Greatly enhanced
0	4	4

Table 6 shows the results for Q3, asking about the ease of comparing Web pages in the VTE-based system. Five participants answered "somewhat easy" or "very easy". Reasons given for the ease of comparison included "Web pages could be related visually" and "the whole workspace could be inspected". Other participants said it was less easy, expressing difficulties with using the system such as "it was difficult to find a target Web page because of the inaccuracy of scrolling by moving the tablet" and "tablet movement had to be performed carefully". One of the participants answered "it is possible to have a 'whole view' in Safari too".

Table 6. Comparing Web pages

Very difficult	Somewhat difficult	No difference	Somewhat easy	Very easy
0	5	2	2	3

As shown in Table 7, most participants answered Q4 by saying that it was easy to relate the positions of views within the workspace. Answers to Q5 revealed that participants used the 'whole view' function to see Web pages opened by other users and to know the positions of Web pages within the workspace. Because only a small portion of the workspace is normally visible, the 'whole view' function was used frequently by the participants.

Table 8 shows the results for Q6. Eight out of the twelve participants answered that they were satisfied with the results of collaborative Web search using the VTE-based system. Their opinions included "everyone could work without being isolated" and "discussion was encouraged because of the increased chances of looking at other users' Web pages". Those users who preferred the standard browser answered "time ran out without becoming familiar with moving the terminal correctly" and "AirDrop was easier to use". During the tasks, some groups obtained good results because of the ease of looking at each others' Web pages and having discussion encouraged, while others spent most of the allotted 20 min familiarizing themselves with the operation of the system and were left with insufficient time to work on the search task.

Table 7. Understanding the position of Web views

Very difficult	Somewhat difficult	No difference	Somewhat easy	Very easy
0	2	0	5	5

Table 8. Satisfaction with search results

Task 1 (Safari+AirDrop)	Task 2 (VTE-based system)
4	8

Surplus or Deficit of Tablets

Observations. Giving four tablets to a group of three users produced different patterns of behavior for different groups. One group used the additional tablet to display the 'whole view', facilitating the comparison of Web pages; individual users continued to use a single tablet of their own. Another group did not use the additional tablet at all. In neither case was any significant change to the amount of discussion, compared with providing exactly one tablet per user, seen.

Giving just two tablets to a group of 3 users resulted in each tablet being used for individual searches, but with two of the users having to share one tablet. Users sharing a single tablet engaged in active communication with each other to perform the Web search. When sharing Web pages with the group, the pages of interest were collected in the center of the workspace as in the case of one tablet per user. Tablets tended not to be moved around the workspace very much, staying close to the participants and their small visible area of the virtual workspace. No significant change was seen in the level of discussion between the users of the two tablets; the tablets themselves were never exchanged while performing the task.

Questionnaires. Question 7 asked users how they handled the tablets when a surplus or deficit of tablets was provided. Participants with an additional tablet answered "the additional tablet was used for the 'whole view' to understand the overall locations of views" and "the additional tablet was not used for much at all". Participants with too few tablets answered that "two users performed most of the searching, with the third user mainly observing the screen" and "the range of tablet movement became restricted".

Table 9. Surplus or deficit of tablets

	Harder	No difference	Easier
$N+1$: 3 users with 4 tablets	0	4	2
$N-1$: 3 users with 2 tablets	3	2	1

Table 9 shows the results of Q8, asking how easy it was to perform the collaborative search. The groups with an additional tablet answered "one of the tablets was used for the whole view" and "we couldn't think of a way to use the additional tablet". The groups with only two tablets answered "the tablet screen was too small for two users to use together" and "only a part of the virtual workspace could be used".

4.5 Discussion

VTE Compared with Standard Browser. Compared with the standard Safari+AirDrop environment, the results show that a VTE-based system increases the chances that users share Web pages with each other and leads to increased user satisfaction with their performance of the task. This is because users can perform the task collaboratively, easily sharing both the process and the results of their searches. Sharing is easy because of several characteristics of a virtual tabletop environment; in particular, being able to see other users' terminal screens and being able to share Web pages instantly within the shared virtual workspace.

A problem arose because of inaccuracies in tracking tablet movement. Difficulties were experienced when trying to move a tablet to a position of interest in the virtual workspace, which consequently reduced the ease with which Web pages could be compared. These difficulties arose from the tracking mechanism used in our prototype environment, and would not be present to the same degree in a VTE using more sophisticated mechanisms. The results do however demonstrate the importance of minimizing the scrolling and positioning errors experienced by users of a VTE.

Number of Available Tablets. When given a surplus of tablets, one group used the additional tablet as a shared 'workspace overview' display while the other group did not use the additional tablet at all. In both cases each user performed the collaborative task using only one of the available tablets. We can conclude that users tend to use a single tablet to perform their searches, and that different uses (including none) can be found by different groups for an additional tablet. With a deficit of tablets, one of the users simply did not use a tablet and instead became an observer of one of the other users. While the communication with their 'tablet partner' was increased, it was difficult for them to contribute as much to the collaborative work.

Users continued to use a single tablet throughout the task, never exchanging their tablet with another user. This suggests that users identify personally with the tablet that they are initially given.

5 Conclusion

We presented a collaborative Web search system built as an application in a virtual tabletop environment, using multiple tablet terminals for display and interaction. Practical experiments evaluated users' use and reaction to the system, to determine the usefulness of a VTE and the effect of changing the number of tablets to create a surplus or deficit. The experimental results show that our VTE-based system promotes discussion and information sharing compared with collaboration using traditional desktop Web browsers.

Future work will include improving the movement tracking in our prototype, with the aim of developing a compact and inexpensive device that can be attached to a tablet to accurately track its location on a tabletop surface.

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