Remote Active Tangible Interactions

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ABSTRACT

This paper presents a new form of remote active tangible interactions built with the Display-based Measurement and Control System. A prototype system was constructed to demonstrate the concepts of coupled remote tangible objects on rear projected tabletop displays. A user evaluation measuring social presence for two users performing a furniture placement task was performed, to determine a difference between this new system and a traditional mouse.

Author Keywords

Tangible user interfaces, evaluation, remote interfaces.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

A tangible user interface (TUI) is a graspable physical interface which is constructed from any kind of physical objects such as Lego™, puppets or coins. Instead of manipulating virtual GUI elements on the screen, such as widgets, through a mouse and keyboard, a TUI invites users to manipulate physical objects that either embody virtual data or act as handles for virtual data. Such physical interactions are very natural and intuitive for us, they enable two-handed input, and provide us with spatial and haptic feedback which aids our understanding and thinking [6, 12]. The physical objects that make up a TUI are referred to as tangibles. Tangibles can be categorized as passive or active.

The use of tangible user interfaces in remote collaboration work is a relatively new area. Recent investigations have gone part way to achieving this goal, but many problems remain. Existing experimental systems are limited by the inability to control the orientation of tangibles, conflict issues when remote users move the same tangible simultaneously, scalability (and related cost of scaling), and occlusion problems with top-projected applications. The main question of this paper is: "*How do you support remote active tangible interactions?*"

The ultimate goal of remote active tangible interactions is for users to experience remote collaboration with a TUI as if all participants were in the same place operating on the same TUI. Users should be able to ubiquitously project their actions to every other client's environment, and be able to feel like they are present at each remote site.

Remote active tangible interactions are enabled by an active TUI, which is physically duplicated at each unique client. An active tangible user interface is one whose state can be changed automatically by a computer without the need for human intervention. This is the fundamental concept of remote active tangible interactions; a user can change the interface state of other clients by modifying their own TUI. The changes are automatically reflected at the other clients.

Due to the focus of implementing an active tangible user interface using an existing technology, questions about the suitability of that technology arise. Therefore, the related research questions are: "*What are appropriate UI metaphors for a distributed TUI?*", "*What UI actions are suitably supported? (E.g. orientation and position.)*", and "*What are the physical limitations of the robots?*".

BACKGROUND

Tangible user interfaces

The work on Bricks [6] is one of the early key works on TUIs. The ActiveDesk application developed by these researchers implements simple Lego™-like bricks on a table surface, which act as handles for manipulating graphical elements. The system combines space-multiplexed I/O (each input device has a single function) and time-multiplexed-I/O (one input device has multiple functions at different points in time).

Other earlier work on TUIs also focused around Lego™-like bricks, such as Ullmer and Ishii's MetaDESK [14] and Rauterberg et al's BUILD-IT system [10]. The MetaDESK aims to complement (not replace) traditional GUIs with physical interactions. It allows users to move two building models to navigate, zoom and warp a map. The map aligns itself so that the two building models always match up with

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their position on the map. BUILD-IT is a similar TUI, where users manipulate bricks as handles to design a factory plant. Neither system is suitable for active distributed tangible collaboration because the bricks are passive (have no means of self propulsion) and cannot be moved automatically by the controlling system.

TUIs in distributed collaboration

Brace, Ishii and Dahley [2] first suggested the possibility of distributing a TUI. Their PSyBench is an early exploration into replacing traditional video/audio conferencing with tangible interfaces. This system uses Synchronized Distributed Physical Objects (SDPO), which make users think that they are sharing the same objects even though they are remote. The PSyBench is based on two networked motorised chessboards. The limitation of this application is the inability to control the orientation of the tangibles.

The *actuated workbench* project [9] is one of the few tangible interfaces that supports duplex input and output (IO). Magnetic pucks (or non-magnetic objects fitted with magnets) operate on a table surface that is fitted with an array of electromagnets, which are energised to move the objects. Users may slide the pucks around manually, which are tracked by an infrared (IR) vision system able to see the IR LEDs fitted to each puck. The number of pucks simultaneously movable is limited due to the complex magnetic array required to move them, and puck orientation is currently not controllable. The goal of the actuated workbench is to enable computer control of the tangibles.

Everitt et al. [5] specifically explore the feasibility of tangible user interfaces in distributed collaboration work. Their system consists of networked smart boards onto which Post-it™ notes can be stuck for design purposes. A high resolution camera captures the content of newly added notes and stores the image on a central server, which the other client then displays digitally on its smart board. Users can rearrange both tangible and digital notes. Because the notes are not active, faint grey shadows are displayed under each note. These become red when a physical note needs to be moved to a new position.

The Planar Manipulation Scale (PMD) of Rosenfeld et al. [12] implements ‘dumb robots’ to produce a bidirectional user interface. The robots feature motors and two wheels and are freely movable around the table surface. Two pulsing LEDs (for position and orientation) underneath each robot enable tracking. To test their work the authors deployed a furniture layout application, where seven robots representing furniture automatically simultaneously drive to form pre-set room layouts. The PMD is not implemented in a distributed TUI, but is a suitable technology.

DISPLAY-BASED MEASUREMENT AND CONTROL SYSTEM

Kojima et al’s [8] Display-based Measurement and Control System (DMCS) robot system is a tabletop robot/tracking technology, which has been implemented in an augmented game environment. It provides a suitable research platform for an improved distributed active tangible user interface. DMCS has the following advantages: easily scalable, control of orientation, requires minimal calibration, robust tracking system, allows tangibles to be lifted up to 20 cm off the table while still allowing for reliable tracking, and supports both top and rear-projected environments (so occlusion by top-projection can be avoided if need be). Kojima et al’s robot system is a suitable platform for improving on existing work into distributed TUIs. Communication with the robot is two-way. Each robot is fitted with five phototransistors to measure light intensity. A special fiducial marker featuring a gradient from black to white is centred over the set of phototransistors. Each robot sends the brightness values of the phototransistors back to the system, which uses this information to keep the fiducial markers centred over each robot’s phototransistors. Controlling the robot is done by sending signals to the robot [13] via a cable or radio.

REMOTE ACTIVE TANGIBLE INTERACTIONS

The Remote Active Tangible Interactions (RATI) system is a fully featured distributed TUI. This section first highlights the major components that were added to the DMCS, and then explains the interior design application that was developed using this functionality.

The RATI system was developed by adding functionality to the original DMCS system. The DMCS system was extended to allow multiple instances of the application to communicate with each other over a network. This was enabled by a custom XML messaging protocol. Two connected DMCS clients with two robots each were paired together, and robots on either table could be moved and rotated while maintaining a common state between both clients. When a user moves a robot on one table, the paired robot’s movements (linear and rotation) on the connected tables are synchronised together. The enables both sets of robots to reflect their physical relationship with information displayed on the table. Simple virtual obstacles and collision-avoidance was also implemented to prevent robots from colliding with other robots or the obstacles. It is important to note that only one robot was employed for each client.

An interior design application was developed for our evaluation. The RATI and GUI test systems embodied the furniture placement application commonly used by previous TUI researchers [3, 12]. A key difference is that ours was distributed. The furniture placement application supports basic components needed for furniture placement, see Figure 1. The furniture application depicts the following six pieces of furniture as a birds-eye view of a floor plan: chair, couch, fish tank, lamp, table, and TV.

Furniture selection is supported by moving the robot on top of the appropriate image, upon which the image would snap to the robot and move around with it. Only one piece of furniture can be attached to a robot at a time. To avoid any unwanted snapping that could occur while moving the robot around during normal interaction, a tiny threshold was included, which only allowed a furniture image to snap to a robot, if the robot was within 10 pixels of the centre of the image. Once a piece of furniture was selected, the robot took on the role of that piece of furniture and could be moved around as if it was a physical model of that furniture item. This embodies a *costume* metaphor, in which a robot can represent different pieces of furniture at different points in time. The costume metaphor was forced by the limited availability of robots, which only allowed one tangible per environment. Additionally furniture may be selected with six keys on the keyboard. This simplifies and accelerates the furniture placement, but was not an optimal solution as the keyboard detracted from the natural benefits of the RATI. A large textual display indicates what the robot currently represents. Ideally one robot would be available for each piece of furniture, and be permanently bound to that identity for the duration of the application. The RATI version of the furniture application is turn based, to avoid synchronisation problems that occurred during testing when two remote users moved the same robot simultaneously.

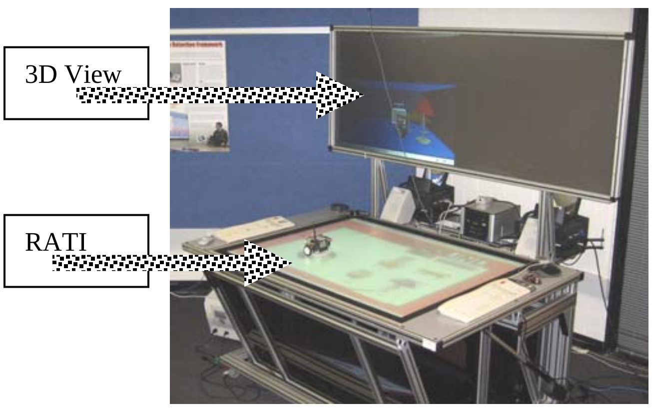

Figure 1. RATI Furniture application

A real-time 3D view of the furniture arrangement provided a second perspective for users, on a vertical screen across the table from the user. The 3D visualization was implemented using the Java3D technology, and provided users with a simple front-on perspective of the room. Figure 1 shows the 3D view of an example layout. The 3D visualization was rendered by a separate computer. The GUI version of the furniture application was kept real-time. This system was fundamentally the same as the RATI, except that users moved and rotated furniture with a mouse.

EXPERIMENTAL DESIGN

The experiment was conducted in the University of South Australia's LiveSpaces facility. Part of the experiment was operated on a NICTA CAT [4] which employs a back-projected, horizontal tabletop display measuring 1320mm x 1000mm. A traditional PC workstation drives the display operating WindowsXP™.

Presence Measures

Two popular measures for social presence are the Semantic Differential measure [7], and the more recent Networked Minds measure [1]. The Semantic Differential measure focuses on the medium's ability to support social presence. Hauber et al. [7] state that media which support a higher level of social presence will be warmer, more sensitive, more personal and more sociable than media with a lower level of social presence. This is evaluated using Cronbach's Alpha, which is a value between 0 and 1 that represents the reliability of the responses collected. A higher score indicates a more reliable result, with 0.7 being the commonly used cut-off value [11]. All eight bipolar pairs from the Semantic Differential measure were included in the questionnaire.

The networked minds measure focus' on an individual's perception of whether or not they experienced a presence, rather than on a particular medium's ability to support social presence. The networked minds measure features three categories; co-presence, psychological involvement, and behavioural engagement [1]. The measure consists of thirty eight questions in the same seven-point bipolar pairs format (ranging from strongly disagree to strongly agree) as the semantic differential bipolar pairs. Our questionnaire did not utilize all 38 questions, but rather only an adoption of individual categories, behavioural interdependence, mutual assistance, and mutual understanding.

User-study Procedure

The users were first given a brief introduction to RATI. After this all participants were introduced to the GUI, and shown how to use it to move and rotate furniture icons. A quick demo was given, after which users were asked to try out the interface to familiarise themselves with it.

Following training, both volunteers were taken into separate rooms to complete the tasks with the GUI interface. Users were separated to simulate the distribution of the collaboration. Each user was given a headset with a microphone for communication purposes. One or two scenarios were randomly chosen from this list for each interface (depending on time availability). Each user had an observer/assistant in the room with them who they could ask questions if they had any queries with the process. After the scenario was explained to users, they were asked to begin. A scenario was classified as complete once both users were happy with the outcome.

After completing two scenarios with the GUI, both users were asked to fill out the first section of the questionnaire. Once the questionnaires were completed, the whole process was repeated for the RATI[1]. Both participants were trained to operate the robots. Participants were made aware of the ability to lift the robots off the surface of the table, and were shown that moving the robots too quickly or lifting

[1] We wish to thank Jumbo Vision Pty. Ltd for their support.

them too far off the table surface would interrupt the tracking. Two user-study assistants took care of switching the turns for the RATI when asked by a participant. After completing the tasks, both users finished the questionnaire.

RESULTS

A total of 20 participants were recruited for the study, and they grouped into pairs for each session. All participants were students from the School of Computer and Information Science, at the Uni. of South Australia. There were a number of user study issues that had an impact on the results of the experiment. These include headset failure, two robot hardware problems, and a software synchronization problem occurred during ~40% of all RATI scenarios. Despite this, 16 of the 20 participants managed to complete at least one successful scenario successfully.

Semantic differential measure results

Short et al's eight semantic differential bipolar pairs were evaluated, calculated with Cronbach's alpha. Interestingly, the Cronbach's alpha calculated for both the RATI (0.42) and the mouse interface (0.33) were quite low. The reported results for semantic differential measures is not statistically significant, but a reflection of the investigator's interpretation of viewing the results. Neither the mouse nor the tangible medium showed the ability to support social presence. This contradicted the hypothesis that the RATI would support a higher level of presence than the mouse due to the natural characteristics of tangibles.

Networked minds measure results

The networked minds questions in the questionnaire were calculated with Cronbach's Alpha. Both the behavioural interdependence and mutual assistance questions measure the degree to which the observer believes their actions are interdependent, connected to, or responsive to the other and perceived responsiveness of the other participant's actions.

The behavioural interdependence alpha of 0.96 was very convincing for the RATI. The GUI also shows a clear support of social presence with 0.84. Mutual assistance did not rate highly for either the RATI or the mouse with values of 0.52 and 0.26 respectively. The mutual assistance indicates the participants worked together more when using the RATI system as opposed to the GUI. The mutual understanding alpha was strong for the RATI, measuring 0.82 versus the 0.74 of the mouse. The alpha values of the RATI were consistently higher than those of the mouse interface, which confirms the hypothesis that the RATI facilitates a higher level of social presence than the GUI.

CONCLUSION

This paper has provided a detailed overview of the concept of remote active tangible interactions, and has made several contributions to the field of tangible user interfaces, in particular distributed TUIs. The remote active tangible interface provides an appropriate metaphor of linking physical objects together for distributive collaboration tasks, such a furniture placement. This was shown through an increase in identifiable networked minds measures.

The user study has shown that the implementation of an active TUI increases the sensation of social presence with users, when compared to a traditional GUI/mouse interface for remote collaboration. In general, users felt more involved when collaborating with the TUI, and felt that the interactions were more intuitive, personal and social. Most users realized that their bias towards the mouse was due to their extensive skill with that input device, and were positive that a mature TUI implementation for distributed collaboration would be a useful medium to work with.

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