Performance Improvement using Data Tags for Handheld Spatial Augmented Reality

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Abstract

Mobile devices such as some recent phones are now fitted with projection capabilities that support Spatial Augmented Reality (SAR) and require investigation to uncover new interaction possibilities. This paper presents a study measuring user performance in a search and select task using a tracked handheld projector and data tags, a 3D physical cue. This physical cue is used to mark the location of hidden SAR information. The experiment required participants to search for virtual symbols presented on two 5ft, multi-sided control panels. Two methods of presenting AR information were employed, SAR alone and SAR with the inclusion of physical cues to indicate the location of the information. The results showed that attaching data tags, compared to virtual content alone lowered the overall task completion time and reduced handheld projector movement. Subjectively, participants also preferred the combination of virtual data with data tags across both task variations

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1 Introduction

This paper describes an investigation into the use of physical aide-mémoire objects; data tags (Figure 1(a)), in conjunction with a handheld Spatial Augmented Reality (SAR) projection device (Figure 1(b)). Deployed as physical targets into the SAR environment, *data tags* aims to improve the user performance when finding and sequencing hidden virtual information. A user study involving a bi-modal interaction technique demonstrates performance improvements when employing data tags in this role, where the non-dominant hand controls the handheld SAR projection device, while the remaining interaction occurs with the user's dominant hand.

Spatial Augmented Reality is a specialized form of augmented reality where projectors produce registered augmentations onto real physical objects [Raskar et al. 2001]. Digital models of the physical objects are used to correctly calibrate a projector's location and orientation within the real-world, allowing augmentations to be correctly registered [Raskar et al. 2001]. Recently, with the increase in availability of mobile handheld projectors, SAR has evolved into incorporating mobile and interactive solutions [Hang et al. 2008; Zhou et al. 2014].

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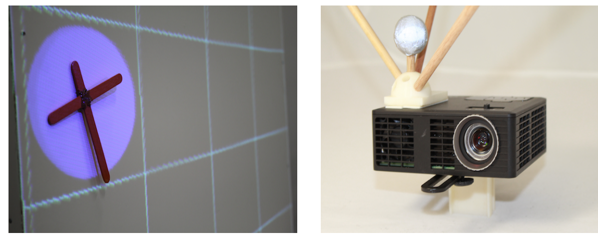


(a) (b)

Figure 1: *(a) Data Tag – (b) Our handheld SAR prototype*

Raskar et al. [2004] describe a technique for interacting with a self-describing world with a handheld projector, using the projected light to gain a response from RFID tags with connected photo-sensors. Beardsley et al. [2005] elaborates on these ideas combining registered augmentations on physical elements in the environment, and projecting static desktop imagery, allowing for projector movement to control user input instead. Using this approach, Forlines et al. [2005] conducted a user study ascertaining the benefits of zooming into areas of projections for selection tasks, with findings showing a reduction in error rates when compared to regular pointing. Cao & Balakrishnan [2006] presented bi-modal interaction techniques combining a handheld projector with a stylus, however their work focused on projecting on planar surfaces.

Collaborative AR research has focused on synchronous approaches. Video based solutions, including video conferencing [Kato and Billinghurst 1999] and remote expert guidance [Fussell et al. 2004] are designed around the re-creation of information, with transmitted content that is not intended for future instruction. Where asynchronous systems have been previously presented, the interactions are tied to planar surfaces, such as a white board [Everitt et al. 2003] or a wall [Cao and Balakrishnan 2006].

Everitt et al. [2003] produced a tangible, collaborative design board, using post-it notes for providing more concise spatial context to the digital discussion. The system allowed both hand-written and digital notes to be expressed on their board, allowing collaborative, non-temporal collaboration to occur between colleagues. Kjeldskov et al. [2009] presented a similar metaphor that supported asynchronous interactions with their FrostWall system, using a translucent two-sided display deployed in an office corridor. In previous work we applied post-it note artefacts to reduce the seam between the digital and physical worlds [Irlitti et al. 2013], allowing workers the opportunity to place physical objects to act as both visual anchors, and a tangible form factor for the attached digital information.

Our research helps further evaluations to be performed in the handheld projector interaction space. As the availability of projector-equipped mobile devices improves, the need for new interactions and evaluating their performance will help mature this technology. The research presented in this paper begins to explore how user performance can be measured when using the combined physical and virtual environments. The application of this research can be applied to CSCW, by exploring combined methods for interacting with and accessing in-situ information.

2 User Study

A user study was designed to compare the performance of searching within an annotated environment, with and without the aid of data tags. Participant's performance was measured while locating virtual symbols augmented into the physical environment. The workspace consisted of two control panel shaped objects that were divided up into several regions (see Figure 2). Each region could possibly contain a single symbol. The configuration of symbols in regions formed a scene. The measured interaction with a scene fashioned a trial. This task is motivated by an asynchronous collaboration domain, where an environment has been previously annotated by a colleague. To validate our results across a range of approaches, the experiment was conducted across two varied tasks; *Find* and *Repeat*. We discuss each of the tasks further in the next section.

2.1 Task Conditions

The experiment was implemented as a two-phase study with the following approach; 2x2, 2x1 within subjects repeated measures design. Two display types were evaluated within the experiment, *cue* and *no_cue*. The *cue* trials would present virtual symbols with a data tag attached to their location, while *no_cue* trials would present virtual symbols alone. The sequence length of every trial was four. The ordering of symbols was randomized throughout each trial. Each symbol sequence was randomly distributed as calculated from a random starting position however the distance between two consecutive symbols was calculated to adhere to the use of both consoles. Symbol sequences could exist within any three of the console regions; α, γ, and δ (see Figure 2). The experiment was broken into two separate tasks, conducted in a strict ordering. The first was the *Find* task, the *Repeat* task as the second.

The *Find* task directed participants to find and select symbols presented across the two consoles. The interaction required participants to use a data tag and perform the *selection* interaction, whilst also using the projector. This is illustrated in Figure 3, whereby a participant would initially search for a symbol (a), find a symbol (b), then interact with the symbol, using our *selection* interaction (c). This figure illustrates a physical scenario, with the presence of data tags on the physical artifact. This task was also tested using two delivery methods (sequence and no_sequence). The *sequence (Seq)* delivery enforced a procedural interaction with the symbols, in the same sense as instructions or a set of directions. A green symbol would dictate the next correct symbol, while the other available symbols would remain red. Once an interaction had occurred, the next symbol would turn from red to green. This process would continue until all interactions had occurred. Alternatively, the *no_sequence (NoSeq)* delivery did not have selection restrictions placed on the user; permitting them to select any ordering of symbols. This delivery simulated a check-list structure.

The *Repeat* condition tasked participants with finding and understanding the position of symbols on one console, then replicating

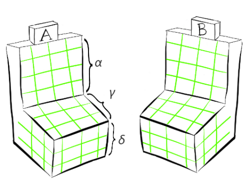
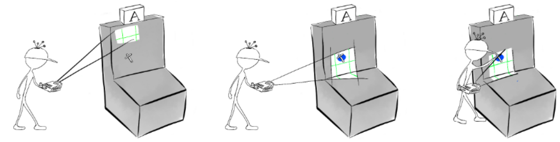
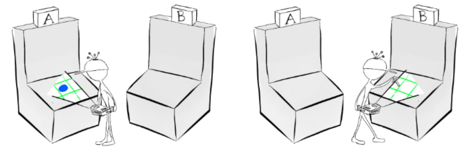


Figure 2: *Position and grid layout of the consoles*



(a) (b) (c)

Figure 3: *An example Find task with the inclusion of data tags*



(a) (b)

Figure 4: *An illustration of the virtual Repeat task procedure*

their positions through the application of data tags on another console (Figure 4). This figure illustrates the procedure with a virtual scenario. Given a physical artifact, the participant would search for a symbol (a), then replicate its position on another artifact (b). This task asked participants to conduct a *tagging* interaction. Unlike the *Find* task, no delivery restrictions were placed on the user's interactions. This task is motivated to expose a user's faith on physical elements when reading a virtual environment. As virtual information is registered, this task allowed an investigation into the impact of physically annotating a scene, and its impact on performance.

The hypotheses tested by the experiment were:

H1 User performance will be faster with data tags compared to virtual symbols alone
H2 Projector movement will be reduced with data tags compared to virtual symbols alone
H3 Error rates will be reduced with the presence of data tags compared to virtual symbols alone
H4 Users will prefer the presence of data tags compared to virtual symbols alone

2.2 Control Panel Design

Two identically sized control panels were used as the workspace. The consoles were laid out in a semi-circle, both positioned at ± 45 degrees from the center point. Each control panel measured at (800x1400x650) millimeters and was divided into 5 sections, including the sides, offering 58 similar sized areas, with a combined total of 116 areas for use in the trials. The area division of each console is illustrated in Figure 2. The consoles were chosen due to their viewing complexity, requiring participants to move around to understand the layout. The semi-circle layout also increased the workspace complexity by placing the outside faces perpendicular to one another. No single vantage point would allow a complete understanding to the state of the workplace.

2.3 Data Collection

During the whole experiment, the total completion time, the first interaction time, subsequent interaction times, number of errors (where applicable), projector movement, and trial success were recorded. The total completion time was delineated by the starting of the trial by the supervisor pressing start and by the participant finishing the last required interaction. All data were recorded during these periods. An error was dictated by the incorrect interaction or replication of a symbol. Dependent on the phase, this would be determined by interacting with a red symbol or placing a data tag in the incorrect location.

The translational and orientation tracking data from the handheld projector was recorded from the tracking system at 100Hz. To calculate movement, the change in location between each sample was recorded. This incremental change was summed together to provide the total accumulated trial movement. To calculate the accumulated rotation, for each sample, a direction vector was calculated, and compared to the previous sample. The absolute value of this rotation was incrementally added to provide the total accumulated rotation for each trial.

2.4 Questionnaire

To complement the data recorded during the session, at its conclusion, each participant was asked to complete a questionnaire. The questionnaire was divided into two sections. The first assessed the user's experience of using the handheld projector with the following questions on a five point Likert scale:

1. I found the projector easy to operate
2. The projector was comfortable to hold
3. I was able to project everywhere that was required
4. It was easy to use the stylus (*data tag*) and hold the projector at the same time to complete the tasks
5. It was easy to place the markers (*data tags*) and hold the projector at the same time to complete the tasks
6. The projected information was easy to understand

The second part of the questionnaire addressed the user study, asking the following three questions for each task variant on a 2 choice opposing visual analogue scale comparing the contrasting *display types*:

1. Locating the targets was easier in the X task
2. Locating the targets was faster in the X task
3. I located the targets with higher accuracy in the X task

Participants were then asked to rank their preference of *display types* across the two task variants.

2.5 Hardware Specification

An Optoma ML750 LED handheld projector was used, with a resolution of 1280x800, and brightness of 700 Lumens. The projector weighs 380g with dimensions 105x106x39 mm. A small bracket was attached to the projector, giving a handle for holding, and a mount for initial calibration at the beginning of each session. The AC cabling was connected to the ceiling along with the attached HDMI cable, which delivered the projector's video signal. Three ceiling mounted NEC NP510WG projectors were used by the study instructor to assist in the placement of data tags when required. A twenty camera OptiTrack tracking system was arranged to encompass a $30m^3$ working volume. The system tracked the ML750 handheld projector and four 3D interaction data tags.

2.6 Experimental Methodology

Participants were asked to complete the trials as quickly but as accurately as possible. Throughout the study, participants were asked to wear a sling bag containing the power supply of the projector.

Four training sessions containing a single symbol were given at the start of each session. Each training session incrementally exposed the interactions of the study. The first and second exposed the searching of virtual symbols with the handheld projector, while the third and fourth added a data tag interaction tool, with and without the aid of a data tag cue. Following this training, a familiarisation paper task was performed that required participants to locate symbols and note their positions on paper documentation containing a planar projection of the workspace. The participants would find a symbol in the same manner as the find task.

At the beginning of each phase, the participant was trained on their expectations during the following trials. The participant would stand 2 meters away, with their back to the consoles. A wall projector would relay pertinent information to the instructor, allowing the next trial to be assembled. When instructed, the participant would turn around 180°to the right and walk into the workspace, and perform the required interactions. At its conclusion, the wall projector would provide directions to the participant to return back to the starting point.

For each participant, the initial *display type* (cue and no_cue) for each task was statistically counterbalanced to distribute the learning effect. For each task, the display type condition was repeated twice. The Find task also had the delivery sequence condition repeated twice resulting in 12 trials per session. At the conclusion of the session, each participant was asked to complete a questionnaire (see Section 2.4).

3 Results

There were 22 participants who took part in the experiment, primarily recruited from the staff and students in the School of Information Technology and Mathematical Sciences, at the University of South Australia. One participant suffered from color-blindness, due to the selection of colors in the Find task, their results were excluded from the study, bringing the total number of participants down to 21. Eighteen participants were male, while the remaining three were female. Eighteen participants had a dominant right hand, while the remaining three were left-handed. The subjects were aged between 19 and 66, with a mean age of 28.3 (SD = 10.23). From the group of 21 participants, for 10 participants, this was their first experience with an augmented reality system. From 252 trials across the two tasks, only a single task ended as a failure. The data from this exercise was not considered for further analysis. The group means and standard deviations for each independent factor were calculated for task completion time. Any trials with a completion time greater than 3xSD were also excluded from further analysis. This resulted in an additional three trials being excluded. Unless otherwise noted, Mauchly's test indicated that the assumption of sphericity had not been violated in the ANOVA analysis.

3.1 Task Completion Time

Task completion time was defined by the *overall* total time taken from the initiation of the trial, to its completion by the participant. To better understand the task, we further examined the variations between the initial search and orientation (*first interaction*) and the time taken from that point to the conclusion of the trial (*remaining interactions*).

Find: The overall mean completion across all independent conditions was 19.58 seconds (SD = 4.91). Under further examination, the mean time to first interaction was 5.51 seconds (SD = 1.62) while the mean time for remaining interactions was 14.04 seconds (SD = 3.91). The means for each independent condition can be found in Table 1. A 2-way independent repeated measures ANOVA analysis was performed across all conditions. Overall, there was a significant main effect of display type $F_{1,20}$ = 33.84, p <.001, the use of a cue lowered the task completion time. There was also a significant effect on the delivery method $F_{1,20}$ = 9.74, p = .005, presentation of symbols without a sequence lowered the task completion time. Examining the first interaction, there was significance found in the delivery method $F_{1,20}$ = 21.15, p <.001, however there was no significance found in the display type $F_{1,20}$ = 1.17, p = .292. The remaining interaction time proved a significance in the display

		Total Completion Time				Time to First Interaction				Time for Remaining Interactions			
		sequence		no_sequence		sequence		no_sequence		sequence		no_sequence	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Find	cue	17.895	5.87	15.86	5.32	6.31	2.62	4.39	1.66	11.58	4.6	11.48	4.39
	no_cue	24.08	7.19	20.46	6.32	6.54	2.34	4.82	1.41	17.46	6.81	15.64	5.83
Repeat	cue	-	-	38.47	9.88	-	-	6.96	2.12	-	-	31.51	8.62
	no_cue	-	-	46.17	12.96	-	-	8.26	3.49	-	-	37.91	10.94

sequencing of symbols was not tested during Repeat tasks

Table 1: *Mean Task Completion Times*

type $F_{1,20}$ = 27.633, p <.001, but not in the delivery method $F_{1,20}$ = .977, p = .335. Overall, the participants were able to complete the tasks with a statistically significantly lower completion time when the symbols did not require a particular sequence. This was also supported in the first interaction time, with statistically significantly lower times to the first interaction when finding symbols that did not require a particular sequence. The sequencing of symbols did not hold when completing the interactions, with only the use of data tags presenting statistically significantly lower times taken to complete trials, compared to trials with virtual symbols alone. Across all three conditions, (overall, first, remaining), there was no significance of interaction between the display type and delivery method.

Repeat: The overall mean completion time for the Repeat task across all display type conditions was 42.32 seconds (SD = 9.77). The mean time to first interaction was 7.61 seconds (SD = 2.71), while the mean time for remaining interactions was 34.71 seconds (SD = 7.75). A breakdown of independent variable mean completion times can be found in Table 1. A paired sample t-Test was performed on the independent factors. Overall, a difference of 7.7 seconds of less time with a cue for mean completion time, BCa 95% CI [-13.26, -2.14], was significant t_{20} = -2.88, p = .009. This illustrates the performance of data tags lowering the total time taken to complete the task over the condition without the presence of data tags. Based on Cohen's d, this result represented a medium-sized effect (d = .668). Further examination also proved statistical significance for first interaction time (-1.3, BCa 95% CI [-2.22, -0.38], t_{20} = -2.95, p = .008) and remaining interactions (-6.4, BCa 95% CI [-11.93, -0.867], t_{20} = -2.41, p = .026) when data tags were deployed into the environment. Cohen's d evaluation represented medium sized effects (First: d = .45, Remaining: d = .666).

3.2 Errors

The mean number of errors across all display types conditions were *Find:* 0.119 (SD = 0.2321), and *Repeat:* 0.7857 (SD = 0.5436). Paired sample t-tests were performed on the independent factors for each task. The differences were not significant (p >.05).

3.3 Projector Movement

The movement of the projector was logged, recording both the translation and rotation properties. These were separately analyzed to gain a better understanding of how the participants moved the projector in the different conditions. The Repeat task was evaluated using a paired sample t-Test over the independent factors, while the Find task used a 2-way independent repeated measures ANOVA analysis across the independent factors.

Find: The accumulated mean projector translational movement for the Find task across all independent conditions was 8.896 meters (SD = 1.38) (*Cue/Seq:*M = 8.56, SD = 1.69, *Cue/NoSeq:* M = 6.82, SD = 1.7, *NoCue/Seq:* M = 11.17, SD = 2.39, *NoCue/NoSeq:* M = 9.03, SD = 1.98). There was significance found in both the delivery method $F_{1,20}$ = 32.655, p <.001, and the display type $F_{1,20}$ = 44.373, p <.001. There was statistically significantly less projector translational motion during the cue condition and for when the symbols were not presented in sequence. There was no significance of interaction between the *display type* and *delivery method*. The accumulated mean angular projector movement across all independent conditions during the Find task was 1784.40°(SD = 669.07) (*Cue/Seq:* M = 1686.2°, SD = 827.9, *Cue/NoSeq:* M = 1507.3°, SD = 1011.9, *NoCue/Seq:* M = 2270.3°, SD = 1005.9, *NoCue/NoSeq:* M = 1673.8°, SD = 825.6). There was significance found in the display type $F_{1,20}$ = 9.923, p = .005, while delivery method $F_{1,20}$ = 4.137, p = .055, did not show significant effects. There was statistically significantly less projector angular movement for the participant when data tags were employed. There was no significance of interaction between the *display type* and *delivery method*.

Repeat: The accumulated mean projector translational movement for the Repeat task across all display type conditions was 17.74 meters (SD = 3.47) (*Cue:* M = 16.64, SD = 4.05, *NoCue:* M = 18.83, SD = 3.8. During this period, an accumulated mean angular projector movement of 3589.80°(SD = 1297.96) was recorded (*Cue:* M = 3587.4°, SD = 1492.9, *NoCue:* M = 3592.2°, SD = 1377.3. A difference of -2.18m, BCa 95% CI [-3.86, -.51], was significant t_{20} = -2.72, p = .013, for the effect of data tags on a projector's travel, while the difference, -4.75°, BCa 95% CI [-564.56, 555.06], was not significant t_{20} = -.018, p = .986. Under further analysis by Cohen's d, the significant result for projector travel represented a medium-sized effect (d = .556). The effect of accumulated projector rotation showed a negligible effect (d = .003).

3.4 Questionnaire

Each participant was asked to respond to the six questions from Section 2.4 relating to the handheld projector, and its coupling with a detached interaction tool. Generally, participants found the projector easy to operate, and strongly agreed that it could produce the information they required (mean score $<$ 2.0). Participants found the projector comfortable to use (Q2), however this significance was not as substantial. Participants strongly agreed that the combination of the handheld projector with autonomous data tag interaction tools, both as stylus, or placed data tag was easy to use. For the 3 questions relating to each task (7-9), a one sample t-Test analysis was performed on the results against a baseline of 50 (neutral). Each test showed statistical significance towards the preference of data tags *(0)* than without data tags *(100)*. In addition to the nine questions, participants were asked to rank the display type across the two task variations. The results clearly show a strong bias towards data tags, with a total of 30 (N = 42) responses favoring an annotated scene involving data tags.

PROJECTOR			
Q1	M = 1.48	SD = 0.602	Mode = 1
Q2	M = 2.67	SD = 1.017	Mode = 2
Q3	M = 1.95	SD = 0.973	Mode = 2
Q4	M = 1.43	SD = 0.507	Mode = 1
Q5	M = 1.57	SD = 0.507	Mode = 2
Q6	M = 1.64	SD = 0.856	Mode = 1

Table 2: *Projector Likert Responses*
1 = Strongly Agree : 5 = Strongly Disagree

4 Conclusion

The presence of data tags had a significant positive effect on performance, lowering completion times and reducing projector movement. These results show support for our hypotheses H1 and H2. When searching for virtual symbols, the presence of a data tag reduced the search space, guiding a user to the location of virtual content. This is confirmed by examining projector movement in the Find Task, which illustrated a significant reduction in angular and directional movement (H2).When examining the breakdown of mean completion times, it is apparent that the difference lies in the remaining interactions after the first selection. Participants were able to locate the first symbol, however the presence of data tags reduced the search space significantly, allowing a superior performance locating the remaining symbols (H1). This contributes a desired effect when considering an asynchronous approach. Users have a superior awareness of their workspace, reducing the energy required to locate and view attached virtual content. Error rates across both tasks were also extremely low, with only a small number of participants contributing to a large percentage of trial errors. Statistically, no significance was found with the presence of data tags. The results did not support hypothesis H3 across both tasks.

Our qualitative results illustrate the substantial preference towards the presence of data tags (H4). Participants commented on physical cues allowing for faster selection in the Find task, and assisting in the judging of distances in the Repeat task. One participant even mentioned they tried to not look at them, as they felt the searching with our projector was more fun without their aid. The projector itself was well received, with a significant number of participants showing preference to its design and output. The bi-modal interactions with our data-tags and handheld projector were seen as intuitive and easy to combine. Some participants commented on the comfort and heat generated from the device, however a better design which separates the mounting bracket from the handle, is lighter and is wireless should improve this result.

This paper has presented an evaluation to the performance capabilities of assisting virtual search tasks with the addition of data tags. The current projector prototype was developed with the assumption that future mobile phones, tablets and handheld electronics will be equipped with projection capabilities that can present SAR information. The view frustum of the handheld projector allows users to move around physical objects while the projection information is updated, making it appear attached to the physical objects. The limited FOV means only regions of the physical objects can be enhanced with projected information, and the experiment explores the space by considering how physical and virtual cues will affect user performance. Asynchronous collaboration has been illustrated as an effective area for embracing this solution, with data tags offering both navigational and storage capabilities to co-located collaborators. With handheld SAR, bi-modal interaction allows for the creation and discovery of spatially registered, in-situ annotations in the workplace. It is envisaged that data tagging will be used in synergy to assist with challenges including memory recollection, information transfer and interaction tasks.

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