Challenges for Asynchronous Collaboration in Augmented Reality

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Figure 1: Asynchronous Collaboration takes place over an extended time duration. As each collaborator provides their input, the retained subject knowledge is increased. Augmented reality asynchronous collaboration information can provide greater context for collaborators, as both producers and consumers, both in the short term and long term. (a) A producer can create a number of annotations, clustering related data into single annotations. (b) A consumer can review this information, and also be provided with temporal information and author’s stress levels. (c) The consumer can revert to a producer, updating the underlying annotations to show modifications to the process. The ! mark illustrates an important change, while the arrow provides navigational cues to further information. (d) A consumer can review the completed and new information.

ABSTRACT

Collaboration is a promising area of investigation for Augmented Reality (AR) applications. While there have been numerous examples of co-located and remote synchronous collaborative AR applications, there has not been the same interest in pursuing asynchronous interfaces. Asynchronous processes differ from their synchronous counterparts due to the collaboration occurring over a period of time, without the requirement of all parties being present simultaneously. For AR applications, asynchronous collaboration is typically considered to be the combination of drawn registered annotations, and their review at a later time. The potential on offer far exceeds this stance. This paper uncovers a unique opportunity for pursuing asynchronous collaboration support in AR, identifies how communications can be enhanced, and discusses the research challenges unique to asynchronous collaboration in AR.

1 INTRODUCTION

Synchronous collaboration affords the simultaneous communication between stakeholders, allowing for the repetition of information exchange to achieve an end goal. The experience in asynchronous collaborations differs due to the variation in time between stakeholder’s input. As users are not working at the same time, the communication requires the retention of produced information, and its consumption at a later time. Collaborative interfaces are generally built around the assumption that synchronous communication streams will be available to support the collaborative technology [8]. Face-to-face collaboration is supported by the combination of speech, gaze, gestures and non-verbal cues to assist in the relaying of communication between one person to another [25]. The physical environment also provides a grounding for discussion, assisting in the spatial understanding and context for the communicated knowledge, while the physical objects themselves are also used to help support thinking and communication [10]. However, due to time constraints, multiple stakeholders are not always available to participate in synchronous exchanges. Under these circumstances, asynchronous collaboration would be required, with multiple entities working together collectively at different times to achieve an end result. The act of this communication exists in the CSCW space: “Same Place / Different time” [24]. This consideration poses a number of unique research challenges for augmented reality.

Current examples of collaborative AR research have focused on the synchronous nature of collaboration, using the technology as a means to enhance the shared workspace [6, 1, 17]. Both co-located [25] and remote [2, 4, 17] synchronous collaboration require multiple stakeholders to be present to provide input at the same time. Producers of information are aided by the ability to repeat lost or ambiguous information, either through speech, or non-verbal cues such as augmented directions. Asynchronous collaboration does not benefit from this quick ability for error correction. While this
form of collaboration has been considered as a sort of virtual graffit[i] [38], there is a lot more to consider than this statement intends. While information is retained for future examination, the onus is on the producer to be as clear and concise with their instructions to reduce the potential for ambiguous or incomplete instructions. Consideration is needed not only about how a single annotation is produced and consumed, but also how multiple annotations are related and coexist within an environment to portray an underlying message. The main contributions of this paper are as follows:

- Defining the differences in research challenges for asynchronous collaboration compared to its synchronous counterparts,
- Specifying key challenges and considerations for asynchronous collaboration, and
- Examining research directions for extending asynchronous collaboration beyond the scribings of virtual content and its consumption at a later time.

Industrial applications offer a compelling domain for the investigation of AR to assist in communication during asynchronous tasks [23]. With distributed locations, shift work, and multiple levels of management, information is consistently required to be relayed between stakeholders at different times. Domains such as manufacturing, engineering, construction, design, renovation, landscaping, maintenance and architecture require further investigation to support communicating applied knowledge within a process from one person to another asynchronously [28].

2 BACKGROUND

2.1 Collaboration

Collaborative AR systems were initially based on face-to-face experiences using handheld and head Mounted Displays (HMD), such as Rekimoto’s Transvision [36], and Billinghurst et al.’s SharedSpace [9]. User evaluations concluded that AR could significantly enhance face-to-face collaboration by merging the task space and communication space that are often separated in desktop systems [7]. This combined shared space allows participants to use the same non-verbal cues used in face-to-face conversations while also interacting with AR content appearing in front of them [25].

Researchers have also used the projection of images onto surfaces to support face-to-face collaboration. For example, the Illuminating Clay interface [34] projects virtual graphics onto a sand table, which can be manipulated by multiple people. LightSpace [42] uses multiple depth sensor/camera combinations to enable the sharing and interaction with SAR content on physical surfaces, and Dyadic [6], a large scale room projection, has enabled two face-to-face users to synchronously interact within a shared virtual scene.

While research has focused on synchronous, real time collaboration, there has been less work on using AR for asynchronous collaboration. Mobile systems have been developed allowing the deployment of virtual tags in space as messages for other users. An early example, MAGIC [37], supported fieldwork for archaeologists using a tablet and HMD, allowing the creation and viewing of AR messages in space. More recently, the Tag it! system [31] used an HMD with a depth sensor to allow users to drop virtual tags in space, registered to objects or locations. There have also been numerous commercial examples of AR browsers, including Junia and Sekai Camera, allowing users to drop AR content to be revisited by friends at a later time [18]. Similarly Irlitti et al. demonstrated a tagging container for the creation and containment of virtual information [22], while the retained information could be retrieved and viewed later using handheld SAR [23]. Collaborative boards have also been presented by Everitt and colleagues [14] and Kjeldskov et al. [26]. These systems use a planar interaction surface, similar to a whiteboard, allowing users to leave asynchronous messages for one another.

2.2 Annotation Authoring

Authoring is key for the production of augmented content [27]. Early approaches restricted creation to desktop environments [19, 20], however to truly support collaboration, there is a requirement to allow for the creation of in-situ information to communicate change and directions [24]. Techniques for directing users to perform tasks have been illustrated within various examples of synchronous collaboration, including drawing on transmitted video feeds [2, 40] or the video transmission of gestures [4, 16]. These forms of annotations are focused on supporting the verbal communication between collaborators in synchronous processes.

Free hand expression of content directly into the environment has been demonstrated by Marner and colleagues [30] and Bandyopadhyay and colleagues [5]. Both solutions use statically mounted projectors and a tracked stylus to allow the creation of digital ink in the environment. Cao and Balakrishnan [11] express a similar principle, achieving similar results using a handheld projector. Zaeh and Vogl [43] demonstrate a hybrid spatial augmented reality projector/video see-through tablet system for programming industrial robot paths using a stylus. The scribings allows the manipulation of target locations, and the generation of motion paths, laser projected into the environment.

2.3 Guidance

There has also been growing interest in applying AR in industrial settings [15, 32, 35]. Typically, these examples are focused on providing visual enhancements for improving task performance. Caudell and Mizell [12] demonstrated an early AR prototype system for assisting wire harness assembly, with numerous applications extending this research for industrial assembly tasks [15, 33]. AR has been used to improve welding processes on automobiles [13, 44], improve quality assurances and maintenance processes [39], improve task localization using AR when working within confined and complex spaces [21], and confirmed performance benefits when completing procedural tasks [29]. These applications illustrate the fundamental benefits to using AR as a means for consuming information during work processes.

3 DIFFERENCES IN COLLABORATION SPACES

The best example of a ubiquitous asynchronous collaboration tool is electronic mail, where information can be delivered to recipients for reading at a later time. While e-mail and paper allow for the communication of two-dimensional representations of information, AR provides the ability to communicate registered information within a three-dimensional environment. While existing research has considered the production of information (annotation authoring), and the consumption of information (procedural guidance), the asynchronous combination of these motivations has seldom been considered. The role of asynchronous collaboration should be considered more complex than the simple drawing of messages for consumption at a later stage. This area of collaboration requires further investigations into a number of potential directions. The following is a list of possible further topics of investigation:

- Provide accurate interactions for authoring, and the creation of relationships between spatial annotations,
- Temporal spatial annotations from user creation,
- Temporal ordering and clustering of information,
- Passive temporal annotations from user actions and behaviour,
- System awareness from previous user actions and behaviours,
- Collective synchronization from multiple deployments, allowing for remote in-situ asynchronous collaborations,
- Visualisation of situated annotations,
  - Overview, Zoom and filter, Details on demand [41].

This list is not exhaustive, but highlights some key areas of investigation needed to realise the potential for AR asynchronous collaboration. Expanding on the previous interpretation of asynchronous collaboration, the ability for accurate authoring of communicated data is an important step to support the ongoing collection of temporal information. The importance of time should also be reflected in the numerous means for creating and retaining information, allowing annotations to be ordered or clustered. While direct user input is a large focus of collaboration, asynchronous collaboration can also benefit from passive inputs including: a) behavioural, the way a person behaves in response to the situation, b) emotional, the way a person feels in response to the situation, and c) temporal, the influence of time to the situation. As time passes, there will be a degradation of a person’s ability to communicate their stress, focus, or duration of time taken for a completed task. Recording these attributes while a task is being undertaken can improve the overall associated communication. The combination of a number of varying factors can provide a more complete picture to the collaborator consuming the information.

A unique consideration for asynchronous collaboration is the ongoing collection of temporal information, from singular or multiple sites. This information can be used by the collaborative technology to provide assistance to processes being completed by a collaborator, or highlight common issues within a process. Information visualisation is a key area to consider effective ways of interacting and consuming with this type of data while performing either role within an asynchronous collaboration.

4 **ASYNCHRONOUS COLLABORATION OPPORTUNITIES**

While synchronous collaboration inherently combines the roles of producers and consumers into a single entity, allowing for the quick transmission of communication through verbal or non-verbal cues, the importance of time in asynchronous collaboration requires the separation of these two roles. Interactions and visualisations suitable for the consumption of information, may not be required or suitable, for the production of information.

An opportunity exists to pursue alternative approaches to annotation retention for asynchronous collaboration. As illustrated in Figure 1, asynchronous collaboration takes place over multiple days. Throughout the collaboration, producers will create information, while consumers will retrieve information. Interactions can be extended to not only include direct spatial interactions with key points of interest, but also provide time based information relating to time spent at particular locations (b), or navigational cues (c), both within and between processes. The temporal ordering of actions not only provides context to a higher level process, but also provides additional context to its producer’s carried out actions.

Multiple spatial actions can be clustered to represent a related process (a), while additional passive behaviours including eye gaze, and emotional attributes (b), can also be annotated within the collaborative technology. Asynchronous annotations can also benefit from verbal and visual cues through rich media [22]. As opposed to being provided as an attachment in an email, or as a printed document, AR affords the rich media to be associated to a spatial position within the three-dimensional environment, offering a greater context to its reviewer.

The capturing of both direct and passive interactions allows for a much broader range of information to be collected throughout a collaboration. An operator’s direct system input, along with their captured behaviour, provides a larger story to the conducted processes and potential issues. As opposed to synchronous collaborations, experts can provide input to a problem with spatial considerations at their own times, while also having a much deeper understanding of the role of the local consultant. While this process is not seen as a replacement for synchronous meetings, it does provide a suitable precursor to allow the learning of subject matter before time critical meetings are conducted.

The collection of temporal information also provides the opportunity to investigate system learning and awareness, built through interactions from both producers and consumers. While passive and direct interactions are used as input, previously documented behaviour within a process can be expressed to highlight inconsistencies with data, or missed steps in a process. While this behaviour can also be provided in synchronous collaboration, there is a larger onus on the human subjects to highlight issues and relay their concerns to their fellow collaborators.

5 **APPLICATION SPACES**

Asynchronous collaboration processes are an integral part of industrial domains. Harnessing the strengths of AR to improve the underlying communication between collaborators is seen as a promising area for investigation in a number of application spaces, including the automotive sector, maintenance applications, design meetings, and Building Information Management.

Augmented reality has already been demonstrated to support workers operating on the factory line, with work by Zhou and colleagues [44] using SAR to project welding locations onto an automotive chassis in a welding work-cell. Extending this process to allow for the accurate in-situ documentation of changes would be the next evolutionary step. As information will inevitably be reduced during a verbal hand-over; introducing a third party will generally lose important directives. The importance of this is demonstrated by lack of communication being one of twelve documented major causes for maintenance related aviation incidents [3]. Outgoing technicians need to be capable of recounting all critical steps and processes to provide the incoming technician with insight into the current state of the repairs. Retaining the temporal actions and behaviour of engineers would improve and complement the traditional face-to-face meetings undertaken at the end of shifts. Spatial annotations would also provide a consistent communication medium, reducing the inevitable information degradation from third party communications.

Design meetings taking place over multiple locations at various times are another application space suitable for the retention of spatial actions. With amendments being carried out between designers and stakeholders, the use of AR provides the opportunity to revisit previous ideas and brainstorming sessions, while also allowing interactive manipulations to be experienced. The three dimensional expression using AR can help with the understanding of ideas, as a design moves through its many changes of its evolutionary life cycle. This evolutionary process is suitably applicable to the Building Information Management workflow, a process which encompasses the large scale retention of digital and physical information representing a facilities characteristics throughout its lifetime. The continuous modification of retained documentation applies suitably to the highlighted features of asynchronous collaboration using augmented reality. Documentation can be enhanced by including not only the registered spatial information, but its organic change through meetings, construction, and amendments.

6 **CONCLUSION**

This paper has presented a number of opportunities for pursuing asynchronous collaboration in AR. AR provides the opportunity to retain registered information within the three-dimensional workspace. To complement existing industrial processes, AR research in asynchronous collaboration must move beyond the sim-
ple scribbling of information for review at a later time. Capturing a worker’s direct, and passive, actions and behaviours, would provide fellow employees with a much broader range of information to assess when confronted with decision making from past experiences.

While there have been numerous research investigations into synchronous collaboration using AR, the problem of asynchronous collaboration has been rarely studied. While there are some similarities between the two forms of collaboration, there are a number of differences that are not covered by synchronous collaboration and require further investigations: a) The temporal attributes of the collaboration. Consider the role time plays in collaborative exercises and how it effects outcomes. b) The retention of annotations for consumption at a later time. How to capture annotations from various forms of input, and how is this information re-visualized at a later time. c) The lack of simultaneous communication streams including verbal and non-verbal cues to support the collaboration. Communicating beyond spatial annotations; how the importance of each form of communication stream influences collaboration.

ACKNOWLEDGEMENTS

The authors wish to thank members of the Wearable Computer Lab for proof reading this paper and Neven ElSayed for her illustrations. This work was supported by a grant from the CSIRO.

REFERENCES


