Contact Augmented Reality:   
Exploring its Design and Implementation

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Figure 1: The tPad is a transparent portable device implementing Contact Augmented Reality for active reading tasks.

# ABSTRACT

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We present Contact Augmented Reality (cAR), an approach to augmented reality where a transparent display is mobile and on direct contact with the augmented object. By following an iterative and user-centric design approach we identified interaction techniques cAR devices and organized them in three categories: contact-based, content-based and off-contact. We built two prototype cAR devices and explore their usage for active reading tasks. A first low-level prototype is a tabletop-based simulation with trans-parent tangibles and allowed us to iterate quickly over alternative designs. The second and higher-level prototype, called the tPad, is a 7’’ touch LCD display with an external camera and resting on a light-table. A paper document is placed on the light-table and the tPad is placed on top of the document. The tPad uses the external camera to determine the document, location and orientation via feature tracking. We collected initial user feedback and elaborate on the HCI and technical challenges to address before realizing this technology.

## Author Keywords

Contact Augmented Reality, Transparent Portable Devices, tPad, Transparent Displays, Tablets, Active Reading

## ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User Interfaces: Input Devices and Strategies, Interaction Styles

## General Terms

Design, Human Factors

# INTRODUCTION

We are witnessing a new trend in display technologies where the display itself is transparent and allows one to view both virtual content and physical objects at once. Most conceptual demonstrations of this technology [5, 6, 9, 12] resemble existing augmented reality (AR) applications [2, 4]. One less explored space is that of directly resting the display on top of a physical object, such as a paper form, a book or a map. This direct contact provides spatial align-ment between the display and object at a very short distan-ce, allowing us to create a mobile augmented reality which does not present the registration and rendering complexities of traditional mobile AR displays [3]. We call this approach *Contact Augmented Reality* (cAR). In cAR registration is reduced to identifying the current document and finding the *relative* 2D location and orientation of the cAR device on-top of it. In cAR rendering no longer requires perspective corrections.

By following an iterative and user-centric design approach, and taking Active Reading [1] as a sample application area, we identified interaction techniques cAR devices. We group these into three categories: 1) *contact-based,* 2) *content-aware and* 3) *off-contact interactions*. Some of these interaction techniques are already known like translation and rotation. However, there are some unique ones like content lookup, hand-written triggers, UI orientation to content, device flipping and stacking of transparent displays. We mapped such interaction techniques to known active reading tasks [REF]. The following scenario illustrates the usage of a cAR device and how it differs from current AR technologies:

*Jane, a foreign anthropologist, is reading the daily newspa-per at a café when she finds an article with the transcript of an interview with a known researcher. As it pique`s her interest she retrieves her tPad, puts it on the table, and glides it over the image in the article. tPad retrieves the video associated with the interview and plays it on the right half of its display. As she watches the interview she moves the tPad over the article and through the left-part of the screen taps on the words unknown to her for translation. Jane realizes there might be an error with the data, then she quickly scribbles the # sign on the edge on the page and moves the tPad over it launching a calculator. After finding the error she moves the tPad back to the problematic answer, highlights a few sentences and scribbles the calculation error. Further down she finds the name of the reporter. Jane taps on the name and asks tPad to perform a Google search for the person. Jane finds the authors website, selects his email address and flips the tPad bringing up the email editor. Jane writes him about the calculation error selecting both the highlights and the scribbles supporting her point. Jane’s colleague Mark shows up at the café and starts discussing the interview with Jane. He puts his own tPad on top of the paper and shows Jane his own comments and highlights. Stacks her tPad on top of Mark’s and moves them in tandem around the document “grabbing” Mark’s content she finds interesting. Once home, Jane reviews the annotations and highlights from her home computer and saves them locally for later study.*

We built two cAR prototypes which helped us explore and apply such interaction techniques. The first prototype is tabletop-based with transparent tangibles, enabling the rapid prototyping and testing of the interaction techniques. The second prototype is a mobile device called the *tPad* (see Figure 1), allowing us to face challenges unique to such standalone device like registration and color-mixing.

Our contributions are at the conceptual, interaction design, and technical levels. First, we introduce cAR and differentiate it from existing AR approaches. Second, we identify a series of interaction techniques for cAR. Finally, we present two cAR prototypes with their software and hardware components, and show how cAR can be applied to and benefit an every-day task such as active reading.

# RELATED WORK [1 page]

cAR augments a physical object with digital information via a transparent display portable device that lays directly on top of it. It builds on work on transparent portable devices and magic lenses. It also relates, to a lesser degree, to other works on technological support for active reading.

### Augmented Reality

*Augmented Reality* (AR) enhances the real world by embed-ding digital content onto it. Bimber and Raskar list three challenges AR faces at its basic level: display technology, registration and rendering [3]. The display technology used determines the complexity of the other two. *Traditional AR* relies on mobile displays carried by the users (retinal, HMDs, smartphones and handheld projectors), allowing the augmentation of virtually any object within the display’s field-of-view but requiring complex operations for regis-tration (e.g. 3D location, object recognition) and rendering (e.g. field-of-view calculation, perspective correction). Moreover, mobile displays present limitations in terms of resolution, focus, lighting and comfort.

On the other side, *Spatial AR* (SAR) relies on displays fixed in the environ-ment (projections, transparent LCDs); requiring simpler operations for registration and rendering and offering solu-tions to the limitations of traditional AR, but limited to non-mobile applications [3].

How we are different

### Transparent Handheld Devices

Transparent handheld devices have been the topic of several concept designs which range from mobile phones to tablet computers [5,6]. Such concepts are instrumental in pro-posing novel interaction techniques and features, some of them similar to the ones explored in this paper; however they are short in discussing appropriate usage contexts and technical limitations. Nonetheless, a few devices are reaching the public like the Lenovo S800 phone [8] and several electronic components companies outline the production of such displays as production objectives for 2014 and onwards [REFERENCES].

Limited HCI and interaction design (IxD) research can be found on this type of devices. For example, LucidTouch and LimpiDual.

Field studies of AR also shed some light on the challenges ahead for transparent handheld devices. For example, XXX et al. describe color mixing as a major obstacle for

### Magic Lenses and Tangible Views

Augmenting upon contact is also inspired by Bier et al.’s Toolglass and Magic Lenses. Toolglass and magic lenses widgets were designed to sit between the application and the cursor to provide richer operations and visual filters on the digital content below. For example, a toolglass widget could have different areas and map unique operations to them, such that by moving the toolglass on top of the target object and clicking through the toolglass the digital content could be modified in different ways. Similarly, the magic lens widget could hide or show details of an underlying digital object by simply resting on top of it. Several projects have built on top of this concept with X

Similarly, the tangible views seek to do something similar but with tangible objects on top of a tabletop display.

Our work draws inspiration from both but here

Mackays ABook – say that we were inspired by this work and we generalize this initial exploration into the concept of cAR. However, we depart in several ways: first we use a camera based registration, second we explore off-contact and content-aware interactions, third we rely on transparent display technology.

# Contact Augmented Reality – cAR [1/2 PAGE]

Sketch figure of Jane’s scenario – probably where she’s watching the video and consulting the translation of the words she doesn’t know about.

Figure 2. The cAR concept -

We introduce Contact Augmented Reality (cAR) as a particular case of augmented reality where a handheld device with an optical see-through display rests directly on top of the object it augments with the display aligned to it.

Our understanding of cAR is guided by the vision, portrayed by Jane’s scenario and illustrated in Figure 2, of users placing their transparent handhelds directly on top of paper documents they want to enrich with digital properties. Key to this vision is users place their devices on any paper document and do not have to hold their device on the air; the device rests on the document or on the table and the user moves it in and out of the document when digital functionalities are needed. This vision acknowledges the affordances of physical objects like the naturalness of interacting with them; in the particular case explored in this paper is the convenience of reading on printed paper. A consequence of this vision is cAR devices augment only when in contact with the augmented object, with the device working as normal mobile device when it is not on top of an augmentable object or in the air.

This vision also extends to other surfaces like a map or a poster in the wall, and any other object where the device could be overlaid. The fundamental requirement is for the device to be able to establish a frame of reference with the object as the center of its coordinate system, and to locate the device in relation to such frame of reference. In this sense, cAR takes distance from traditional and spatial AR systems which determine the location of both the display and the augmented object in three dimensions[[1]](#footnote-1). cAR requires to know the location in two dimensions from the frame of reference of the object’s coordinate system; i.e. using a cAR device on a book while in bed or while sitting on a table makes no difference when determining its location.

3) Simplified rendering

5) Rests on the table (not as tiring)

6) Not always present – as a support tool rather than focal, as an ambient display

Why does it need a transparent display: 1) because it preserves the appearance (texture, colors, lighting, age, wear) of the object being augmented.

2) Because if maintains visible the physical modifications done in that object.

3) because its convenient to preserve the affordances of physical displays/objects like he intuitiveness of grabbing and moving them, bring it close and take it away.

A contact augmented reality device serves X purposes:

* integrated display and input device
* enhances physical objects with digital functionalities
* leverages natural tangible interactions

# RESEARCH Approach [1/2 Column]

The main contribution of this paper is to investigate the notion of contact augmented reality in terms of the possible interaction techniques and the implementation challenges for their realization. For this purpose we engaged in a three phases research approach. In the first phase we engaged in a user-centric design process in order to give wider validity to our ideas. To effectively involve users and ground the design discussion between researchers and with the users we used “active reading” as a scenario and inspiration tool. We chose active reading because it is an activity users are familiar with and, as shown later, facilitates the elicitation of concrete design choices. Moreover, active reading leverages the affordances of paper [REF, REF] and benefits from digital functionalities like e.g. search and copy+paste [REF, REF, REF]. We ran several design sessions in two distributed teams in two different countries, our methods included brainstorming, focus groups and semi-structured interviews. By imagining a cAR device running an appli-cation for active reading, both the research team and participants could brainstorm and illustrate how such cAR device could support better active reading. This led to particular interaction techniques and applications features.

In the second phase we built a proof-of-concept cAR simulated device using a tabletop computer and transparent tangibles. This implementation is further described below, and was used to explore multiple interaction techniques and early architectural design challenges for an actual device.

In the third phase we built the tPad, a prototype cAR device using a 7’’ touch-sensitive LCD display, a light table, and an embedded camera. This implementation is also further described below and was used to explore the actual tech-nical and software architecture challenges of such device. Moreover, although far from a future real cAR device, the tPad allowed us to collect initial feedback from users of such systems by exposing them to active reading tasks using the implemented interaction techniques and features.

# ACTIVE READING [1/2 COLUMN]

Adler and Van Doren define active reading as the combi-nation of reading, critical thinking, and learning. Active reading includes tasks such as annotating, note-taking, highlighting, searching and [ADD HERE REFERENCE AND LIST OF TASKS WHERE THERE IS ACTIVE REDING].

A number of research projects propose technical systems to support active reading allowing users to highlight documents, type and/or scribble annotations, and extract and share text. Table [REF] shows an aggregation of existing solutions and the features they support.

Although our goal is no to create an cAR system for active reading that outperforms the existing ones, we use the list of features and outlined in this line of research as a test bed and inspiration source for the exploration of cAR devices. So for example, in the brainstorming and user-centric design sessions, we ask ourselves and our participants how they could support highlighting or annotations with a transparent portable device. As interaction techniques start to emerge, we reanalyzed the active reading features looking for compelling mappings.

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Table 1.

# cAR Interaction Techniques [1 Page]

Describe design sessions – first round:

* Winnipeg, interviews with 6 participants, each had a mock device
* Winnipeg, focus group
* Germany, brainstorm session 1

Second round:

* Winnipeg, brainstorm session 1
* Germany, brainstorm session 2

## Results

Contact-based

* Horizontal Translation
* Horizontal Rotation
* Freezing
* Gestures (flipping, shaking)
* Direct Pointing (pen, touch)
* Adding digital content (highlights, scribbles, notes)
* Interacting with digital content (opening/moving note, remove highlight and scribble)
* Stacking

Content-aware

* Extracting content from object (word look-up)
* Anchoring content to object (highlight search results)
* Orient UI to content flow

Off-Contact

## Mapping to Active Reading

Here we show Sophie’s high fidelity mock-ups

## Implementation Requirements

* Have a model of the surface where it can rest: content, orientation, meta-data
* Locate cAR device in relation to the page
* Touch input

# Tabletop Prototype [1 Page]

Implementation Details: registration, display and render details.

Features

Feedback

Limitations

# tPad Prototype [1 Page]

System overview [IMAGE]

Implementation Details: registration, display and render details.

Features – features that are not contact, reinforce the need of paper

Software architecture

Hardware

Registration efficiency (graphs by Sophie)

Limitations: LCD and light-table, FPS, single-side touch input, attached to the computer

Feedback

# Discussion [1 PAGE]

Model

* Model-based registration: model creation and distribution
* Model-based –vs– ad-hoc registration

Optimization Strategies

* Server-based
* Tagging at the document and page level
* Scaffolding: actual page -> next page -> previous page -> document level -> database
* Accelerometer triggered
* Button triggered

Simplified rendering

* Lower entry barrier: authoring tools and programmers readily available

Color mixing:

* Transparent displays on mobile devices – perhaps not for mobile phones, but convenient for cAR.
* Color correction
* LCD + OLED: can show both real white and real black

Issues of Camera-based Interface

* Potential recognition errors
* Delay for processing
* Dependence on lighting conditions
* Needs lots of computational resources

# Conclusions [1/2 PAGE]

Actual conclusions

Future work

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1. Even projector-based spatial augmented reality systems require knowing the location in three dimensions of the augmented objects in order to do the perspective corrections of the projected image. [↑](#footnote-ref-1)