

University of California, Santa Barbara

Department of Computer Science

Master Degree in Computer Science

Master Project Report

**ResponsiveAR: Dynamically adjusting AR level of detail based on visual angle**

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Abstract

Dynamically adjusting the content of augmented reality (AR) applications to efficiently display the most relevant information is important for user satisfaction. Currently, there is not a common practice for dynamically adjusting the content of AR applications based on their relative size. We present ResponsiveAR which applies the development philosophy of responsive web design to AR application design. We designed the ResponsiveAR algorithm to improve the usability of AR applications at any relative size. Our algorithm dynamically renders textual and symbolic content based on its legibility and viewability respectively. We applied our ResponsiveAR algorithm on user interface elements in Microsoft's Mixed Reality Tool Kit and evaluated usability and scalability through a between-subjects study with 44 participants.

Table of Contents

[1. Introduction 8](#_Toc104839273)

2. [Related Work 11](#_Toc104839275)

[2.1 Responsive Design 11](#_Toc104839276)

[2.2 Activity Centered AR Design 11](#_Toc104839277)

3. [Implementation 13](#_Toc104839279)

[3.1 Object Classification 13](#_Toc104839280)

[3.2 Threshold Determination 14](#_Toc104839281)

[3.3 Dynamically Adapting Content 15](#_Toc104839282)

4. [Experiment Design 17](#_Toc104839284)

[4.1 Training 17](#_Toc104839286)

[4.2 Applications 18](#_Toc104839287)

[4.3 Tasks 19](#_Toc104839288)

[4.4 Independent Variables 20](#_Toc104839289)

5. [User Evaluation 21](#_Toc104839291)

[5.1 Participants 21](#_Toc104839292)

[5.2 Procedure 22](#_Toc104839293)

[5.3 Data Collection 23](#_Toc104839298)

[5.3.1 Subjective measures 23](#_Toc104839300)

[5.3.2 Objective measures 24](#_Toc104839305)

6. [Scalability 24](#_Toc104839307)

6.1 Mixed Reality Tool Kit [24](#_Toc104839307)

7. [Results 26](#_Toc104839309)

8. [Discussion 27](#_Toc104839311)

9. [Limitations/Future Work 28](#_Toc104839313)

10. References 29

List of Figures

List of Tables

Chapter 1

Introduction

In 3D environments the relative size of an application is constantly changing with respect to the user’s position and application size. As a user moves closer to and further from an application, it's relative size will increase and decrease respectively. Additionally, a common user interaction with applications in 3D environments is scaling which will resize the application to the users desired size. The continuous changing of an application’s relative size is a common occurrence in AR making the usability of an application at all relative sizes critical for the user experience and efficient use of virtual content. In addition to usability, user satisfaction with the application's appearance and interaction, for all sizes, is necessary.

A similar challenge has been presented in 2D environments and has largely impacted the designing of web applications. Responsive design is a development philosophy used as an approach to application development, primarily used in web applications, that aims to render applications well for a variety of devices, window or screen sizes. Web pages are able to have a good user experience on desktops, tablets, and mobile devices due to the design methodology prioritization of usability and satisfaction for all display sizes. With the success of responsive design in 2D environments and the apparent need for a dynamic approach to applications design in 3D environments, we developed the ResponsiveAR algorithm to dynamically adjust application content for improved usability at any relative size.

The adaptation of an application’s content to all relative sizes is necessary for user enjoyment and efficient use of augmented space. Therefore, responsive design in augmented reality should aim to create augmented reality applications that are both usable and satisfactory for all relative sizes of the application through the implementation of dynamic changes to an application’s content depending on its scale and position. While designing a solution to solve this problem we developed three primary research questions:

1. Does dynamically changing an applications content based on relative size improve its usability?
2. How distracting is the dynamic changing of application content to users?
3. How does users’ performance change as the applications relative size decreases?
4. How does user performance compare with and without responsiveAR?
5. How distracting is ResponsiveAR to users?
   1. Maybe: How distracting is the dynamic changing of application content to users?

\*Give an overview of what is to come in the paper\*

In summary, the primary contributions of this paper are as follows:

1. We developed the ResponsiveAR algorithm to dynamically adjusts application content based on its relative size
2. We evaluated the ResponsiveAR algorithm used performance tests, scalability, and user experiments
3. We provide a thorough analysis of responsive design for AR applications

Chapter 2

Related Work

2.1 Responsive Design

Responsive web design allows web applications to dynamically adjust to a device’s screen size, orientation, and proportion. This approach is intended to adapt a web page for a diverse range of device screens from a smartwatch to a desktop computer. The development of responsive design came as users began accessing web pages more often on their handheld device rather than their desktop computer. A static webpage was no longer suitable for the variety of devices available therefore developers could either make multiple designs at fixed display sizes or make a single design to adjust to all screen sizes. The success of responsive web design is noteworthy in 2D environments with its ability to improve usability of a web page for such a variety of devices.

2.2 Activity Centered AR Design

The dynamic adjusting of an applications content to efficiently display relevant information is an important field of research within AR. Two notable approaches are Context-Aware optimizations and Level of Detail (LOD) Interfaces.

Context aware optimizations adjust the applications content based on the user's current context to display relevant information. Here information is displayed efficiently through the rendering of relevant information. A current limitation of this approach is the applications use of virtual space. While context-aware optimizations prioritize relevant content, the display of such content is shown limited consideration.

The parameterizing of an applications display information with respect to the distance from the camera was previously accomplished by Level of Detail (LOD) Interfaces. LOD aims to optimize screen space in 3D environments solely based on the applications distance from the camera. However, the display size cannot be adjusted by the user limiting this approach to only consider distance in its implementation. A more effective approach would parameterize applications display of information with respect to its relative size which accounts for both its distance from the user and scale. To address these limitations, we present responsiveAR.

Chapter 3

Implementation

Our goal is to improve the usability of an application at any relative size. This section illustrates how ResponsiveAR helps to achieve this goal by dynamically adapting application content based on its relative size. The ResponsiveAR algorithm examines two key concepts - determining a threshold value for when in object is to be considered usable in AR and transitioning between an object’s usability based on its threshold value. We have divided our algorithm into three parts: Object classification, threshold determination, and dynamically adapting content. For this algorithm we are assuming the device technical specification of the HoloLens2 device which has a resolution of 2k, holographic density greater than 2.5k and see-through holographic lenses.

3.1 Object Classification

In order to correctly determine the threshold for usability of an object, we must first classify an object as one of three groups – text, interactable, or game object. This is because each type of object is a different type of content, and each type of content has different rules for determining usability. The key idea to this algorithm is to only display usable content and remove content that is not considered usable. We will describe the three types of classifications and their rules for determining usability.

* **Text Object:** A text object is to be considered usable when it is legible therefore its usability is based on its readability. Any text object that is not considered readable should not be displayed in the application content.
* **Interactable Object:** An interactable object is to be considered usable when it is large enough for interaction therefore its usability is based on its ability to be successfully interacted with. For example, a button should only be rendered if it is large enough to be selected. Therefore, any interactable object that is not considered interactable should not be displayed in the application content.
* **Game Object:** A game object is to be considered usable when it is large enough to be viewed therefore its usability is based on its viewability. A game object that is not considered viewable should not be displayed in the application content.

3.2 Threshold Determination

Thresholds are determined for an object based on its calculated scale to distance ratio and its object classification. After an object is classified and its rules for determining usability are outlined, a mathematical representation will be given for each object through the calculation of its threshold value. An objects threshold value is its mathematical representation of its usability. We will describe the three types of classifications and how to calculate their thresholds.

* **Text Object:** The readability of text in AR is based on the text height and its distance from the user. The threshold value will be determined by a height to distance ratio. Microsoft typography establishes the minimum legible font height at a distance of 45 cm to be in the range of 3.14mm to 3.9mm. In our algorithm to calculate the minimum threshold for a text object we divided .36cm by 45cm, we determined the threshold to be .008.
* **Interactable Object:** The usability of interactable objects in AR is based on its volume and distance from the user. The threshold value will be determined by a volume to distance ratio. Microsoft establishes the target size for interaction as 3.5cm by 3.5cm for a distance of 200 cm. Based on the target size, we calculated the minimum threshold for an interactable object as (3cmx3cmx1cm)/200cm equal to .045 volume to distance ratio.
* **Game Object:** The viewability of game objects in AR is based on its volume and distance from the user. The threshold value will be determined by a volume to distance ratio. Microsoft has not established a target size for when an object is viewable in HoloLens2. Because of this, we will assume the threshold of viewability to be 10 times smaller than the threshold for usability of an interactable object. Therefore, our threshold for a game object is .0045 volume to distance ratio.

3.3 Dynamically Adapting Content

Objects are shown within an applications content based on their thresholds. If an object’s minimum threshold is met, such that their scale to distance ratio is larger than their minimum pre-determined threshold, then that object is displayed. However, there's a stark transition between rendering and not rendering an object. This can be a startling event to a user because objects do not appear and disappear in the real world. In order to minimize the starkness of this transition we implement a transition strategy based on transparency. When an object has reached its threshold, it goes through a transition stage where it iteratively increases transparency until it is fully visible. A similar approach is taken for when an object ratio falls below the threshold value. It goes through a transition stage where it iteratively decreases transparency until it is invisible.

Chapter 4

Experiment Design

The main purpose of the experiment is to compare the usability of applications with and without ResponsiveAR. We designed a balanced between subjects user study to compare the participants performance and error frequency for application specific tasks. Each participant was assigned to group A (without ResponsiveAR) and group B (with ResponsiveAR). The following subsections will detail the experiment design.

4.1 Training

Each participant was given a set of training tasks and a 40 minute pre-experiment exercise. There were a total of 8 training tasks consisting of clicking buttons, sliding a slate and typing on a keyboard. Additionally, each participant partook in a separate user study evaluating multitasking in AR for approximately 40 minutes giving each participant around 45 minutes of experience using the HoloLens2 before beginning the ResponsiveAR tasks.

4.2 Applications

The applications were designed to represent mobile applications that a user frequently uses in their daily lives. The following describes each application and its intended mobile application representation.

* Article Display: Shown in Fig 1, this application consists of a display of six articles on a sliding slate background. Each article had a title, list of authors, and date of publication. This application is intended to represent a news or blog application.
* Keypad: Shown in Fig 2, this application is a digital keypad with a number display. It has a button set with an arrangement of digits, symbols and alphabetical letters. This application is intended to represent a cell phone dial.
* Weather Forecast: Shown in Fig 3, this application shows the current and forecasted weather for the city of Isla Vista, California. The current temperature in fahrenheit is shown in large text with the location underneath. Additionally, there is the forecasted weather of the low and high temperatures for the day and the predicted temperatures per hour for the next 10 hours. This application is intended to represent a weather application for the user's current location.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Task | Task Description | Application Name | Application Size | Application Distance |
| 1 | click the 2nd article title | Article Display | 0.25m x 0.25m x 0.25m | 0.60075m |
| 2 | click the 5th article title | Article Display | 0.25m x 0.25m x 0.25m | 0.60075m |
| 3 | click the Author of the 4th article | Article Display | 0.35m x 0.35m x 0.35m | 0.60075m |
| 4 | click the Date of the 1st article | Article Display | 0.55m x 0.55m x 0.55m | 0.60075m |
| 5 | type the phone number 949-927-4580 on the touchpad then click call | Keypad | 0.55m x 0.55m x 0.55m | 0.60075m |
| 6 | type the phone number 805-UCSB-EDU on the touchpad then click call | Keypad | 0.9m x 0.9m x 0.9m | 0.60075m |
| 7 | Find the current temperature on the weather application and type it into the keyboard | Weather Display | 0.3m x 0.3m x 0.3m | 0.60531m |
| 8 | Find the current location on the weather application and type it into the keyboard | Weather Display | 0.43m x 0.43m x 0.43m | 0.60531m |
| 9 | Find the low temperature on the weather application and type it into the keyboard | Weather Display | 0.77mx.077mx0.77m | 0.60531m |

4.3 Tasks

The tasks were designed to represent common interactions a user would have with its associated application. For example, the first task is to click on the 2nd article title. This is intended to illustrate how a user would select an article to read. Each task was carefully designed for common use cases for each application in order to accurately evaluate the applications usability.

The experiment is made up of 9 tasks. Each task asks the user to look at the application content to complete an interaction. Each application is displayed at the same distance for all of their associated tasks. However, the size of the application increases for each of its associated tasks. Table 1 details the task’s description, number and its associated application along with the applications size and initial distance from the user.

4.4 Independent Variables

A between subjects user study was run with two independent variables:

* Application: There are three type of applications used Article Display, Keypad, or Weather Display
* Design: The design was one of two types with ResponsiveAR or without

Chapter 5

User Evaluation

Our university’s local human subjects committee approved the user study prior to running the experiment on participants. Before the beginning of the user study, we hypothesized that the ResponsiveAR design would outperform the non ResponsiveAR design in both time to complete and lower error frequency when completing the task. This hypothesis was driven by the idea that less content on an application would allow for increased usability of the available content. For example, the user would be able to find the current temperature more quickly when the only content displayed is the current temperature compared to having all weather forecast information displayed at once. Additionally with less content, the error frequency would decrease given there is less information to be considered.

5.1 Participants

45 individuals participated in the evaluation (26 self-identified as female, 15 as male, 2 as non-binary, and 1 as genderfluid) with ages ranging from 18 to 42 years old. All participants volunteered to participate in the experiment with financial compensation. The criteria for participating in the user study was participants must have a 6th grade English reading level and not have a health history containing seizures or epilepsy. In terms of experience using AR headsets, 21 participants had used an AR headset prior to the study and 24 had not. Among the 21 participants experienced with using an AR headset, 5 were self-assigned experts having used the device over 10 times.

5.2 Procedure

Prior to arriving at the experiment space, participants signed an informed consent form containing the experiment procedure, purpose, risks, and other necessary experiment information. Additionally, they filled out a pre study questionnaire to gather background information on each participant. Each participant was made aware of the goal for the experiment and the recording of their performance for data collection. The experiment was divided into three parts:

Training: As described in section 4.1 each participant had approximately 45 minutes of experience using the HoloLens2 during the training. The purpose of the training was to increase each participants comfortability using the device to obtain more accurate data for evaluating the usability of our applications.

Tasks: Participants completed all 9 tasks knowing the time to complete a task was being measured.

Questionnaires: After completing the training and tasks, participants were asked to complete a post study questionnaire. The questionnaire was used to evaluate their opinion on the usability of the applications throughout the tasks. Our main focus was on the difficulty interacting and reading the applications. We also inquired about the participants’ enjoyment using the applications throughout the tasks.

5.3 Data Collection

Overall, 405 trials were recorded: 9 tasks x 45 participants. For each trail, performance was measure by both time to complete the task and number of attempts made to (error frequency). The users position, applications size and position were collected throughout each task in addition to their eye gaze and hand rays.

5.3.1 Subjective measures

Responses to the 7-point Likert scale (1 = strongly agree, 7 = strongly disagree) measured scores for each component of the questionnaire:

* Application Usability:
* Task Difficulty:
* Content Display:

5.3.2 Objective measures

Chapter 6

Scalability

ResponsiveAR is a C# script that can be added to user interface elements. We applied our ResponsiveAR algorithm on 45 user interface elements in Microsoft's Mixed Reality Tool Kit. We found that 44 of the 45 elements showed expected behavior. The AppBar Collapsible Button element did not show expected behavior. The unexpected behavior was text did not disappear when it was out of the readable threshold value. While applying the algorithm to user interface elements, I analyzed the usefulness of the algorithm for element types.

The Follow Me algorithm ensures an element is always within a specified visual angle. Because of this any element with the “follow me” script applied to it should not use the ResponsiveAR algorithm. This is because the ResponsiveAR algorithm manages the content to be usable at any visual angle. When an element has a constant visual angle, the key benefits of the ResponsiveAR would be used and it would only add extra complexity to the element.

Chapter 7

Results

Chapter 8

Discussion

Chapter 9

Limitations/Future Work

* Have not set maximum threshold when the object is too large to be readable

Chapter 10

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