

ARCAHING: USING AUGMENTED REALITY ON MOBILE DEVICES TO
IMPROVE GEOCACHERS' EXPERIENCES

A Thesis

by

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ABSTRACT

Geocaching is an outdoor treasure-hunting game that uses GPS and mobile devices to assist players in the quest of finding a geocache — a cleverly hidden physical container with a log and other items inside. The current game’s smartphone interface provides the GPS location of a geocache on a map that updates as the user gets closer to the hidden location. However, constantly checking in with the map to correct one’s location can substantially reduce situational awareness, which can become a quite a danger, as the user wanders through the woods or up a cliff to find a geocache. ARCaching is an Android-based augmented reality (AR) mobile application that facilitates navigation to a geocache and also increases situational awareness by combining environmental information gathered by the camera and overlapping it with rendered images to aid the players in their quest. ARCaching uses BeyondAR as an augmented reality browser to guide players to a cache while still providing pertinent information about the environment to help reduce risk. ARCaching was developed and evaluated against the original Geocaching.com application to determine how the user experience is affected by the AR technology. Results showed that AR while geocaching can facilitate the task of searching for caches and improves the user experience.

DEDICATION

Dedicated to my parents, who always supported me in everything.

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I want to use this section to share how thankful I am with God and all the people that contributed in one way or another to make this project possible. First of all, I want to thank my advisor Dr. Tracy Hammond who supported me with this research project and my studies during my time at Texas A&M.

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Contributors

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NOMENCLATURE

App	Application
AR	Augmented reality
Cache	Abbreviation of geocache
Cacher	Geocaching player
Geocache	Hidden object with an assigned GPS location, target to find on the Geocaching.com game (geo = location, cache = hidden storage)
GPS	Global Positioning System

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1. INTRODUCTION

Augmented Reality (AR) is a term that has become well known in the last decade. Being defined as "a live direct or indirect view of a physical real-world environment whose elements are augmented by virtual computer-generated sensory input such as sound or graphics" [1], this technology has proven to have a lot of potential for changing daily life activities, and also to provide new ways of entertainment. AR also brings the opportunity to redefine old existing entertainment methods, and one relevant opportunity to apply and test this fact is the real-life scavenger hunting game known as geocaching [2, 3, 4].

Geocaching is a real-world, outdoor treasure hunting game using GPS-enabled devices. This game has already more than 6 million geocachers (users) around the world that travel in a quest to find hidden containers called geocaches [5, 6, 7]. Approximately 2,753,420 geocaches have been hidden and their geographical position has been saved in geocache servers, Figure 1.1 shows a map with the places around the world where caches can be found. In order to find the geocache, geocachers must download a mobile app similar to Google maps that allow them to track the geocaches using its latitude and longitude values. Directions are displayed over a map, and it is expected from the geocacher to have the ability to read and interpret the map in order to find the right place where the geocache has been placed [8, 5].

For an experienced geocacher, reading and interpreting maps could be a simple job, but for new geocachers, this task becomes hard and tedious since GPS technology is not 100% accurate and reading maps is not common skill nowadays [9]. As a consequence, new players can lose a lot of time looking for the target once they have reached the area marked on the map. Another problem that geocachers face when trying to find geocaches is the way that they are hidden. Sometimes the search can be challenging because of

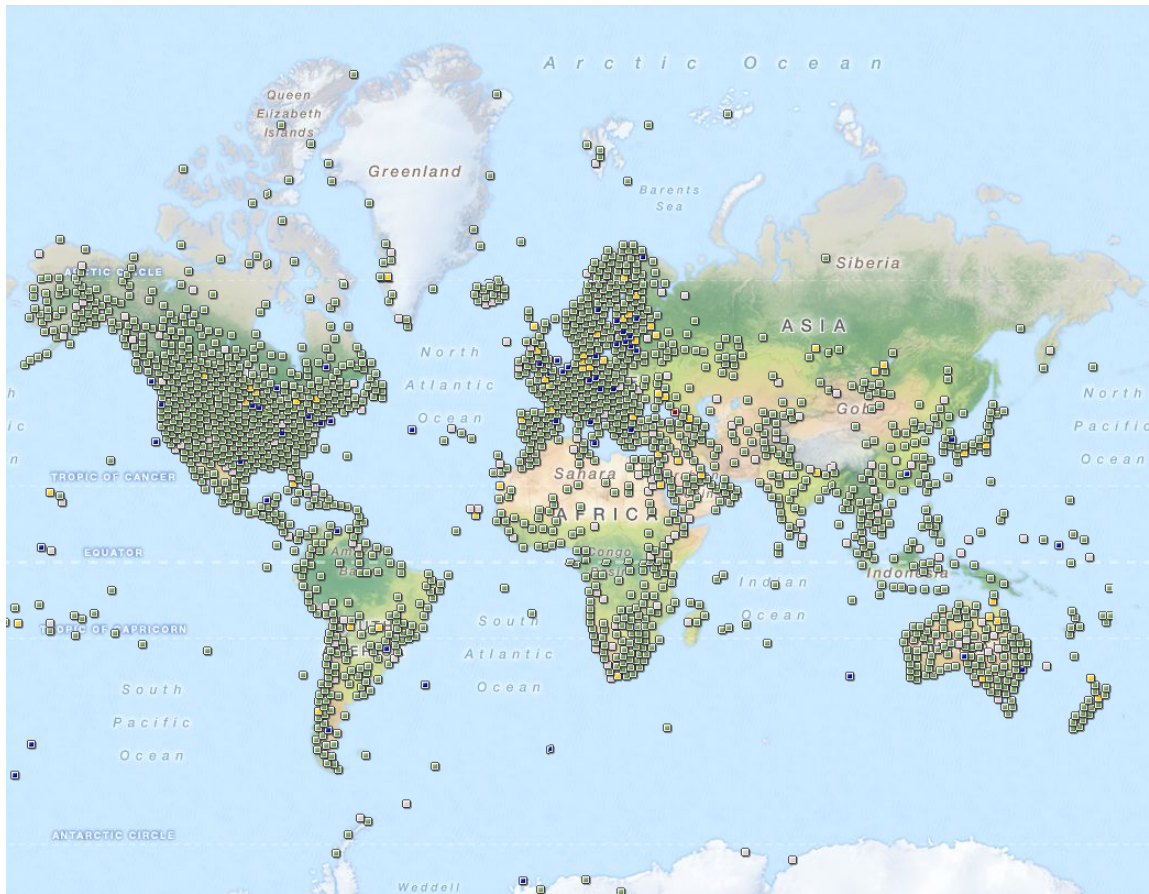


Figure 1.1: Geocaches around the world. Reprinted from: [2]

the clever way they are hidden or simply because of the size of the geocache itself. In order to face this issue, the Geocaching[®] app contains a section where geocachers can write comments about the geocache they are looking for and share their experience with others [2]. Comments may provide clues about the location, the state of the geocache, pictures of the location, or simply whether or not they were capable of finding it. The comments section has proven to be a good addition to the application and geocachers often found themselves looking for clues in this section. However, writing a comment takes time and scrolling down the list of comments searching for useful clues becomes slow and tedious while the number of comments on the list increases. All those problems

negatively affect the user's playing experience.

This research intends to show that using our AR application, ARCaching, to help navigate on the quest to find geocaches can reduce the time and effort required to find a geocache and also help to improve the geocaching user experience. ARCaching is an AR mobile application designed to support geocachers on their quest to find caches without losing environmental information. The app overlaps rendered images over camera information to provide guidance for geocachers to the target cache selected by the player.

The remaining chapters will explain with more detail the work was done and the contribution of this research. Chapter 2, the prior work chapter, provide a compilation of relevant work that has been done on AR and mobile development. The goals and questions that this research aims to answer are explained in more detail in Chapter 3. Chapter 4 explains how geocaching is played and some details about the functionality of the previously existing Geocaching[®] mobile application. In Chapter 5 ARCaching's architecture, user interface and functionality are described in detail. The methodology used to collect and analyze data, and to compare both applications is explained in Chapter 6. Chapter 7 details the results obtained after the data analysis. Conclusions of the research can be found in Chapter 8. Chapter 9 has a discussion about how this research can be further pursued in the future.

2. RELATED WORK

Research in augmented reality, mobile computing, and GPS began in the 90's, and the technology is constantly evolving. This section compiles relevant research completed in those fields that serve as a starting point for the whole research project.

2.1 Technological Changes

Augmented reality has become quite popular recently, and has been applied to a number of different fields, including, tourism [10, 11, 12, 13], driving directions [14, 15], entertainment [16, 17, 18, 19] and education [20, 21, 22, 23]. However, even as AR has recently been popularized by the release of Pokemon Go [19, 24], the research on this topic can be traced up to late 80's when the advances in computer graphics and technology allowed developers to combine the virtual world with the real one. Some of the first applications for AR were cockpit control [25] and surgeries [26]. Both approaches proposed the idea of projecting images directly to the eyes of the user by the use of complex wearable devices.

However, augmented reality is not only limited to overlapping images over camera information. There are many different ways to mix the real world with the virtual one, especially with the development of wearable hardware. Understanding the possibilities that AR and wearable devices could bring together, [27] presented a compilation of available wearable devices and their possible applications on AR technology at that time, along with some new projects that had been developed during that year. Wearable devices presented in the previously mentioned paper included heads-up displays, monocular displays, biosensors, clothing, and other interesting technologies.

Along with the development of AR and wearable devices, another well know technology made started to emerge. The Global Positioning System (GPS), patented in 1993

[28], provided, for the first time, the possibility of calculating the two-dimensional position of an object via satellite signals. However, the system was not considered completely functional until 1995 when the number of satellites available was enough to fully support all system features without having time gaps [29]. The release of GPS for non-military purposes opened one door to a new set of systems, programs, and applications that could be developed, and with that, a new opportunity to change how the world works.

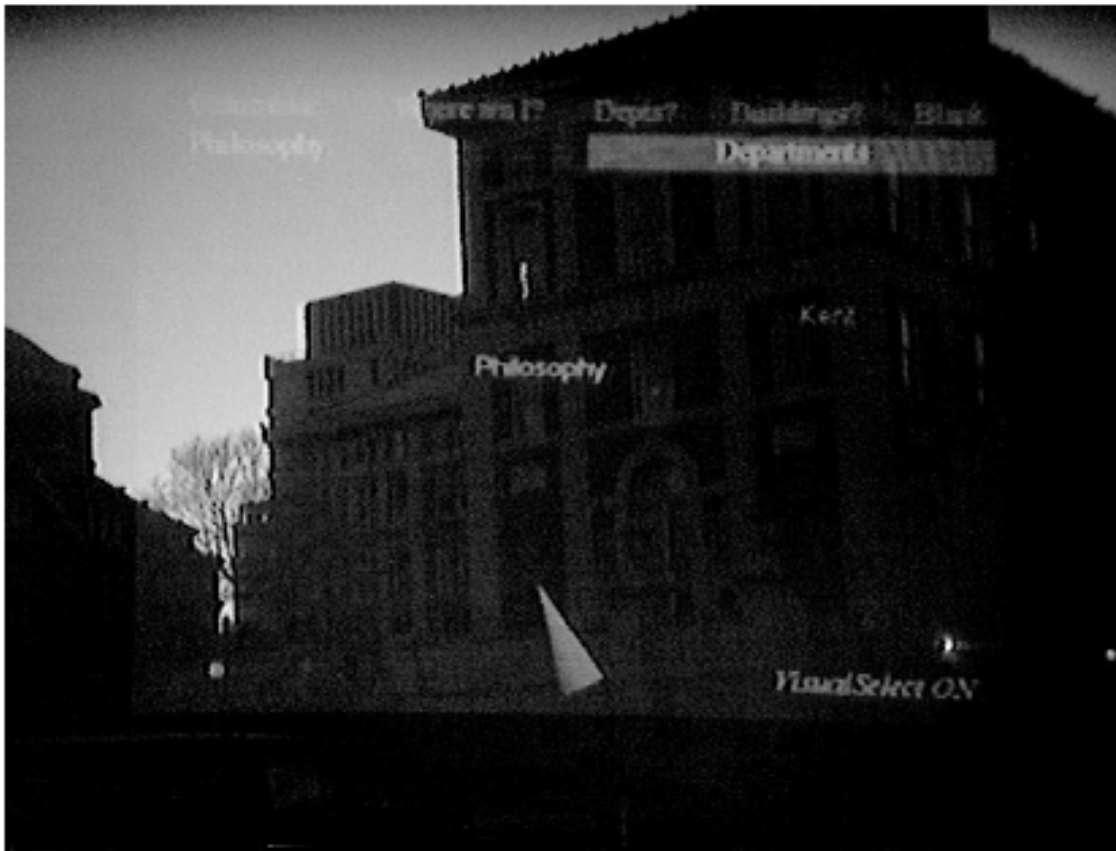


Figure 2.1: Interface of Feiner's prototype. Reprinted from: [30]

It was just a matter of time before the idea of combining AR with GPS came to light. The first prototype that attempted to combine these two technologies came from

the Columbia University [30]. Using a headset based on the model presented by Caudell [31], this prototype used the users location to present information about their surroundings. Figure 2.1 displays this prototype's interface.

The information was displayed on 2D windows arranged in 3D space, similarly to the technique presented in [32]. The users were able to interact with the system using a hand-held device operated with an electronic pen. This prototype was limited to work only on campus and it presented some accuracy and software issues, but it set the first stone for AR-GPS applications.



Figure 2.2: Backpack version of the wearable computer. Reprinted from: [33]

Just one year later [33] presented a new model for Feiner's prototype, but this one was designed to work in a limitless space. This model also got rid of the hand-held device and relied only on the users' location to select and present the information of their surroundings. The tests performed with the GPS proved to have an accuracy range of 20 meters for the users, making this model pretty accurate even for today's standards, but the model presented some issues related to the movement produced by walking, sunlight interfering with the headset and, the most important, a considerable lack of portability that its predecessor also had.

Another attempt to create an outdoor AR system, called MARS, was presented a year later [34]. MARS was a combination of a VR indoor system combined with an AR outdoor system that shared information and worked together in order to improve the users' experience. The view of both parts of the system was synchronized so it was possible to modify whatever the AR device was displaying by making changes on the VR terminal. Despite the new design of the software, the AR terminal followed the same model of the previously designed prototypes. The user carried around a backpack that contained the hardware and the information was displayed over a heads-up set that combined camera input with the information sent by the VR terminal.

All previously mentioned prototypes required the user to carry around a bag pack that contained all the hardware necessary to make the system work, requiring an extra effort to use it and definitely causing some discomfort too. Therefore, portability was desired on any AR application that was intended to work outdoors. Figure 2.2 shows the hardware used on one of this prototypes as an example.

The answer to the mobility issue of GPS based systems came along with the Benefon Esc [35], displayed on Figure 2.3. This was the first mobile phone that incorporated GPS technology among its affordances. After this innovation was discovered by other companies, the inclusion of GPS sensors into mobile devices became a trend [36]. describes

some consequences of the popularization of GPS in mobile devices, and some numbers that prove the huge feature impact that this new feature brought. The inclusion of this new feature also brought new ways to interact with the environment, bringing up some rough attempts of applying AR. [37] presented results from a set of studies performed between different groups of users about ways of interaction with GPS on mobile devices. Some of the ideas that the study presented are: displaying information based on location context, using GPS on mobile devices to give directions and also the idea of creating and share information based on user's location. All these ideas are an important base of mobile AR applications despite that, in those days, the technology was not enough to support an AR system that renders images over the camera in a cellphone.



Figure 2.3: Benetton Esc, first cellphone with GPS

2.2 Current AR Applications

New technology enhancements on mobile devices have brought also new ways of applying AR on life; map reading [38] and translation tasks [39, 40] are just some examples of current uses that AR has on common tasks. The introduction of smartphones and devices that allow users to modify the software by adding or removing applications opened a door for a new market of applications and, as it was expected, AR and GPS were not left behind.

Perhaps the currently best known and most used GPS application is Google Maps [41]. Starting as a desktop application, Google Maps is the widest spread location mobile application in the world. It offers many services as sharing and saving location, searching for places and information and giving directions for walking, driving and using different types of transport. Google Maps also provides open access to its API, making possible to include its functionalities into new applications. This app provides many different ways of interaction, but it does not include AR features into its affordances. However, the open access to the API brings an open possibility to include its best features in an AR app.

Wearable devices also have evolved and open opportunities for developing new applications and revolutionize the world around us. Google Glass is an example of wearable technology that opens room for AR. It can be worn as a conventional pair of glasses but has an impressive computational capability along with a high-resolution camera, wireless connectivity, microphone and a display screen between other features [42]. This technology has been well received among doctors that previously had tried to use AR to improve their surgery methods [43, 44, 42]. Other approaches that wearables have taken are the creation of watches and wrist devices [45, 46, 47], and also other clothing accessories.

One example of wearable devices that has been developed recently and combines GPS and directions is the haptic vest, displayed on Figure2.4. Originally it was designed as a



Figure 2.4: Haptic vest. Reprinted from: [48]

military device for guiding peashooters to beacons in a safer way by not compromising their visibility or hearing capability [48], but the project has evolved to become an alternative direction device for driving motorcycles [49, 50, 51]. The wearable consists of a jacket or vest that contains haptic sensors on the shoulders and the back. These sensors are connected by Bluetooth to a mobile device where computations are performed and use vibration to guide users to their final destiny. The applications have proven to be a success and the creators are looking forward to finding more uses that can be given to this technology. One of those uses is a prototype that provides directions to geocachers by using this vest. It has been implemented by members of the Sketch Recognition Lab at Texas A&M. Tests have been done on this prototype with good, yet not perfect, results of the research promise to be a success in a close future but this research has not been published yet. The results obtained from this project also has been one of the main motivators of ARCaching.

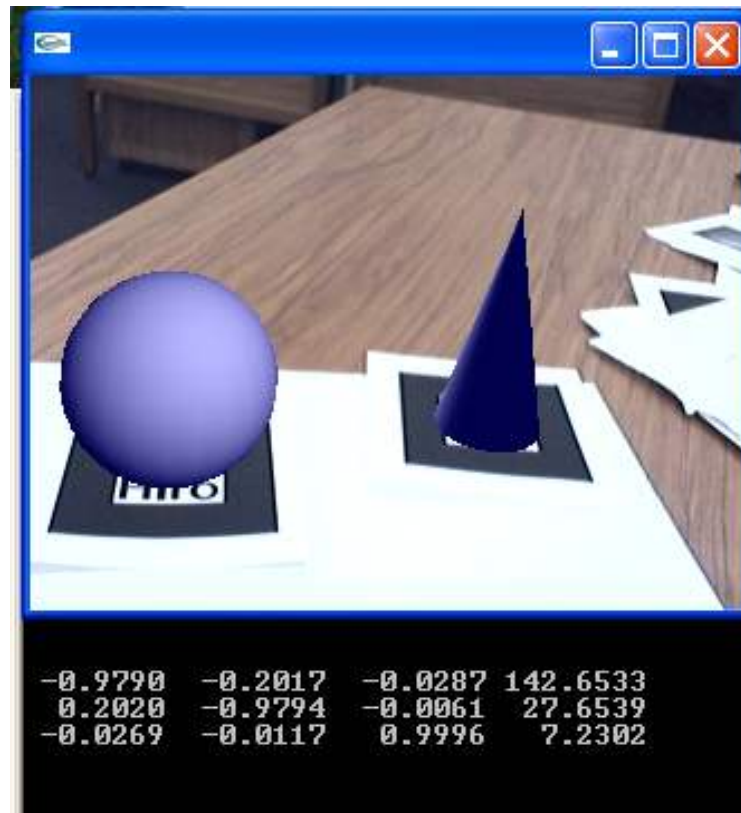


Figure 2.5: ARToolkit

Now, on the AR side, one of the first approaches taken for developers to incorporate graphical AR into mobile devices was the use of printed marks. [52] presented a mobile version of a previously developed software called AR Toolkit. This application is capable of recognizing printed marks by using camera information and rendering a preloaded model on the screen over the current position of the mark. By manipulating the mark is possible to manipulate the position of the model on the screen too. This idea has been taken by Disney who recently presented a mobile application capable of reading the drawings made on coloring books and rendering a 3D model of the character with the same texture on the drawing. [53] The use of printed markers is a clever way to avoid issues with location and just focus on rendering images. Also, it makes easier to manipulate the

rendered objects. However, this approach is limited to work only on places with markers (possibly limited to indoors), and the number of models that can be rendered is also limited by the number of markers available. An example of how this application works is displayed on Figure 2.5.

2.2.1 AR Browsers

The next step on AR mobile development was to replace the printed markers by location information using the GPS system available on the mobile device. Many applications and frameworks that exploit these capabilities have appeared lately and have received the name of "AR Browsers" [1].



(a) Layar

(b) Wikitude

Figure 2.6: AR browsers' interface

The first AR browser released was [54]. Available since 2008 for android and iPhone,

this platform offers many functionalities that can be included into your project, like 3D rendering, proximity triggers and audio reproduction, all this working together with the GPS and compass management [55]. Layar have brought access to its API making possible for other developers to include its functionalities into their projects making many developers to apply AR into different types of application, including truism [56], sharing comments, ratings and recommendations [57] and even to develop some games [58]. Layar's user interface is displayed on Figure 2.6 part A.

Another popular AR browser that came not much time later is [59]. This one poses an interface with Google Maps and its API is relatively simple to incorporate into new projects. One of the first applications that implemented this API was Wikitude Drive [14] used to overlap camera information with driving directions. Wikitude also has tried to standardize the format of augmented reality geo-located objects (Geoobjects) used on AR browsers by creating a standard language called ARML [60]. Wikitude has provided support for many other applications that share social media and Wikipedia information about the user's surroundings. Wikitude's user interface is displayed on Figure 2.6 part B.

As an open source option for those developers that cannot afford to pay for the previous mentioned AR browsers, BeyondAR appears as an independent project that offers geolocated AR support for mobile devices [61]. The features this framework provides are limited in comparison to other paid options but is powerful enough to support many applications and mobile games. Also, developers have the capability to modify the code since it has been published on GitHub.

2.3 AR for Entertainment

Now is clear that mobile devices have the potential to support AR and GPS applications, and that many projects have already started to implement those capabilities with many different purposes. Therefore, is time to give a look for AR mobile applications that

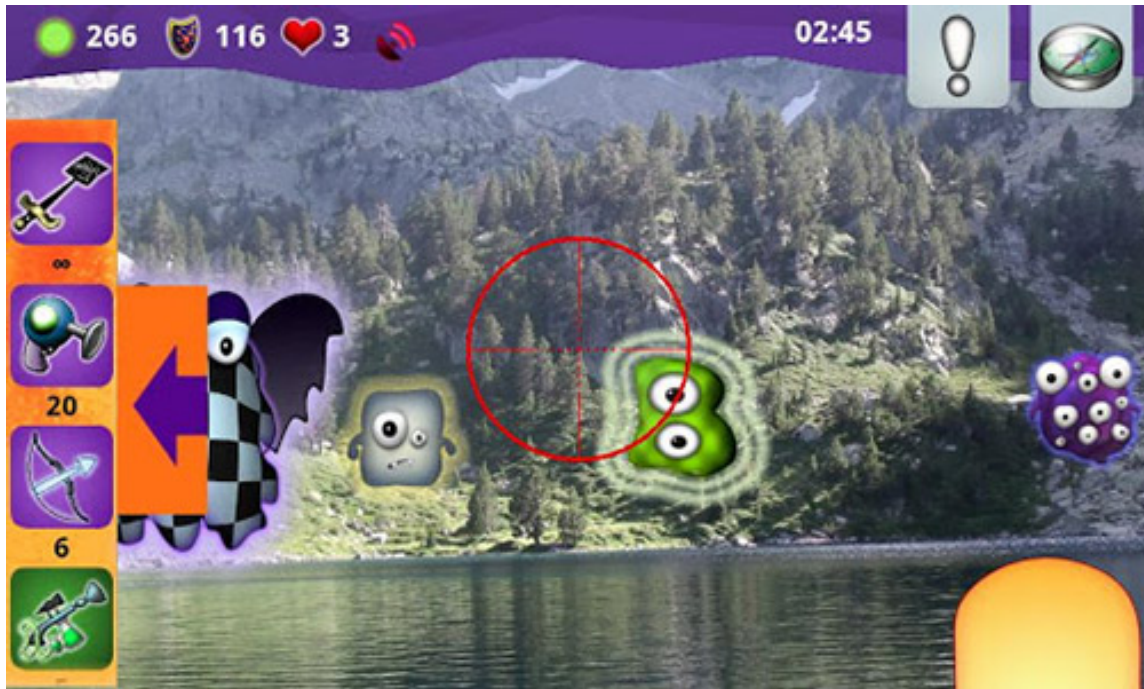


Figure 2.7: Game developed with BeyondAR

have their main focus on gaming or entertainment since that is the topic that ARcaching is pursuing.

“Can you see me now?” [62] presented a clever idea of how to incorporate GPS and mobile devices into gaming. This study presented a version of Tag game where real players were running in a predefined section of a city trying to catch avatars that represented online players. This game combined the real world with the virtual one in something the author called an Alternative Reality (The author avoided using AR since they were not augmenting any of both players’ reality but combining them into a new game dimension). The game doesn’t use camera information in combination with rendering but it totally relies on GPS and Wi-Fi information. One of the most important lessons this paper has to teach to anyone that wants to work with GPS is that there will always be uncertainty since the hardware is not perfect. The important thing is how to deal with it. Some

suggestions are trying to hide it or simply exploit it into the game. GPS technology has greatly improved so the uncertainty will be less than in the past.

Previously it was mentioned that Layar was used to build THEEMPA [58]. This was a treasure hunting game that relied on the user's location to be played. In those days Layar only had supported geotags, that consisted of text boxes that were placed over the camera information. This limitation affected the graphical potential of the game, however, it proved that AR has the potential for "hide and seek" games. Scavenger hunt games as geocache could also take advantage of the lessons and advice that this paper presents about AR gaming design. Some recommendations that this research makes to take into count is local memory management and the local scope that each device will have. Those aspects are critical for the game and it is recommended to consider the advice this paper presents.

One last proof that AR mobile applications with GPS have the potential for gaming and entertainment is Ingress [17], that came as a multiplayer AR version of "the king of the hill" game where players are divided into two factions that fight for the control of important landmarks around the world. In order to gain control of the landmark, players from the same team have to walk to the landmark's location and use the application to deploy digital items obtained in the game. Controlling three different landmarks gives the faction the opportunities of score points by linking them with certain items on the game. The game has become very popular and currently many events have been made around the world. However, while this game is using real world locations to build a new virtual world that is a reflection of our reality, is possible to separate both worlds from one another. The game lacks reality augmentation since virtual and truth realities remain separated.

Currently, the most popular AR game is Pokemon Go [19]. Taking advantage of the popularity that this Nintendo franchise already had, this game uses the same interface as Ingress to make players fight for the control of Gyms (landmarks again), but this time, a Pokemon team is required to be part of the battle. Pokemon appear randomly around the



Figure 2.8: Pokemon Go

world while walking and the app uses camera information and 3D rendering to display the Pokemon overlaying the real world. Players then have to use pokeballs and other items to try to catch the Pokemon and join it to their team. Items can be found in certain locations called Pokestops. Again, players are required to walk to the locations in order to succeed in the game. Pokemon Go had a great impact on society, reaching more than 100,000,000 downloads on according to Google Play entries [63]. It is still not perfect but is one of the most advanced AR mobile applications that had been released so far, proving again the

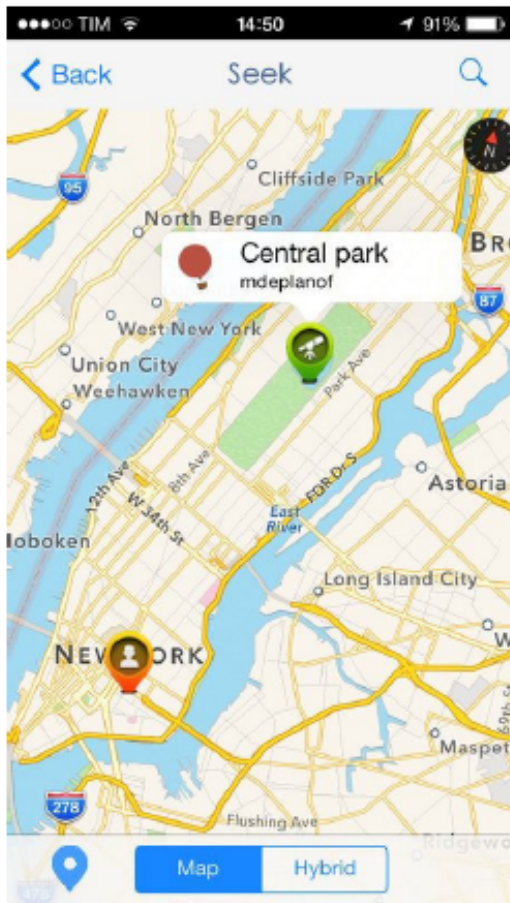
potential that this kind of applications has.



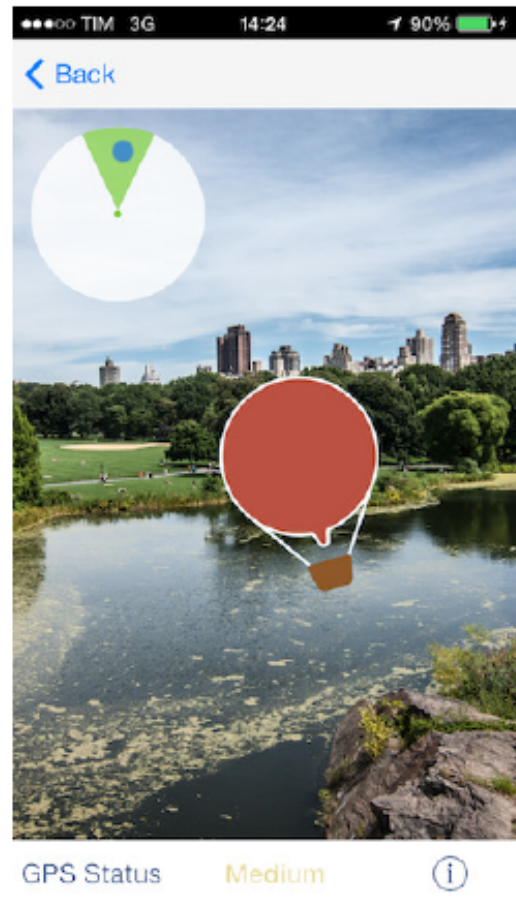
Figure 2.9: Father.io

One last app that is worth mentioning, even though its popularity has not reached the same as the previous games, is Father.io [16]. The game is an AR implementation of laser tag where phones are used instead of guns. Camera information is used to aim and tapping the screen as shooting. HUD information overlays the camera showing relevant information as life, ammo, scope and a radar. This game is also designed for multiplayer using network technology to allow many devices be connected and play at the same time, however, an extra laser device is required to play and maybe this is the reason why the popularity of the game has not caused as much hype as the other two.

The idea of using AR for Geocaching purposes has also been mentioned before [64]. AiRCacher is a prototype that emulates the gameplay of geocaching by deploying virtual caches on specific location given by its coordinates. In order to hide a cache, players have to log into their web application, search for the location on the map where the cache is



(a) Map



(b) Augmented Reality

Figure 2.10: AiRCacher user interface. Reprinted from: [64]

wanted and submit the information. Caches are saved on AiRCacher’s server. In order to find a cache, players have to walk to the location indicated by the virtual cache’s coordinates and use the mobile application to scan around and find an image that represents the cache. The purpose behind it is to study the behavior and motivations of geocachers. Despite having all the features and characteristics that the original geocaching game provides, this application can not be considered as an improvement to the gameplay since it does not help players to find real caches. However, this prototype is a proof that the

idea of combining scavenger hunting with augmented reality is feasible with the current technology. Figure 2.10 shows this app's user interface.



Figure 2.11: Snapchat AR filter

All previous apps and programs present the entertainment from the gaming side, however, the social media franchise has also taken the idea of using AR as a way to provide fun and new ways of interactions between their users. A good example of this behavior

is Snapchat [65] and the new filter options provided by the app that allows the user to take selfies by modifying their face or environment, and share the with their friends and contacts. The idea of using AR filters has become more popular with the time and they constantly switch their filters to keep people engaged with the app. Figure 2.11 shows an example of the AR filters provided by this application.

So far, in this section has been proved that AR and GPS on mobile devices have been evolving, and currently these technologies have the potential to be used for games, entertainment and that many other activities. There is a list of real-life games where AR and GPS have been already implemented. Laser tag, king of the hill, tag, Pokemon and treasure hunting are just some examples of games that successfully jumped from real games to AR mobile app games. This section also proved that the idea of using AR on for geocaching purposes is possible and have been tried once. This is enough evidence for supporting that geocaching could also be successfully transported into an AR app and that this change could also improve the experience that current cachers have on their quests while playing.

3. RESEARCH QUESTIONS

After setting the background and precedents of this research is time to define what is pursued and what are the goals that this research is trying to achieve. These goals have been formulated into two main hypothesis, each of one has their own set of questions. The following sections describe that hypothesis and questions and provide a better understanding of the scope of the present research project.

3.1 An AR Mobile Application Can Improve the Efficiency of Geocaching

According to Tang, AR possess the potential of enhancing performance while executing common tasks [66]. Using this idea as a starting point, the first argument that this research supports is that using AR to help geocachers on their quest can actually make this task easier and faster. There are many ways to test and prove whether this statement is true or not, but not all of them can be tested on the same research. The hypothesis was subdivided into a set of questions in order to limit the proof methods and determine how it will be tested. The questions generated from this hypothesis are:

- Can an AR mobile app reduce the time expended on searching a cache?
- Can an AR mobile app reduce the effort required for the search?
- Can an AR mobile app facilitate to create and review comments?

The answers to these three questions will make possible to find out if there is any improvement on Geocaching efficiency by using AR or if that improvement does not exist, and help to determine whether or not the hypothesis is true.

3.2 An AR Mobile Application Can Improve the Geocachers Experience

Applying AR into any task produces a substantial change in the way users experience it [67, 12, 68], but the real question about those changes is: Are those changes on the experience for good? The second argument supported by this research is that AR can actually make the user experience better and help to make the game more enjoyable. Again, this hypothesis was fragmented into three questions to make easier the search of this answer.

- How the users describe their geocaching experience before and after trying the AR application?
- Will players enjoy more the game while playing with an AR mobile app?
- Will players prefer to use the AR app over the original one?

Having an answer to these questions will help to understand how the Geocaching experience changes with the inclusion of AR, and if those changes are worth the effort of implementing this technology or not.

In general, this study intended to prove or disprove each one of the hypotheses presented here, answer the questions related to them, and use those answers to determine how AR mobile applications might be applied to all sort of scavenger and treasure hunting games and revolutionize this sector of entertainment too.

4. GEOCACHING

This section is dedicated to explaining how the game of geocaching works, and describes the official mobile application that is currently used by geocachers to perform the scavenger hunt.

4.1 The Game

Geocaching made its first appearance as a game near to the year 2000 when the first cache was hidden by David J. Ulmer in Oregon [4]. It took some time before the first website was developed by Mike Teague, however, the number of players and cachers have increased really fast since those early days. The game is easy to play and really engaging. For new players the instructions to get involved are described next [2]:

1. Register an account on the website.
2. Go to <https://www.geocaching.com/seek/default.aspx>.
3. Search nearby caches using a postal code.
4. Select one of the caches that appear on the list.
5. Enter coordinates on a GPS device.
6. Use the device to find the hidden cache.
7. Sign the logbook and return the geocache to its original location.
8. Share the experience online

Along with these steps, the Geocaching community has established three rules that geocachers must observe while playing the game [2]:

1. If you take something from the geocache (or "cache"), leave something of equal or greater value.
2. Write about your find in the cache logbook.
3. Log your experience at www.geocaching.com.

The simplicity that takes to get involve into this game has made the number of members in its community to increase pretty fast.

4.2 Caches

Even when the traditional cache consists of a hidden box or container filled with objects, the game provides more options to make the search more diverse and fun. The official website has listed eighteen different types of caches with a description of them [2]:

- Traditional Geocache - A container hidden at the given location. Size and form of the hidden container may vary. Figure 4.1 displays a traditional cache.
- Mystery or Puzzle Caches - These caches include puzzles that need to be solved before in order to find the cache.
- Multi-Cache - These caches include multiple containers with clues to the final location where the real cache is located.
- EarthCache - Location of a geological location that people can visit to learn more about the earth [69].
- Letterbox Hybrid - This type of geocaches contains clues for Letterbox (another popular way of treasure hunting) [70].
- Event Cache - Gathering of local geocachers or organizations. Date, time and coordinates of the event are posted on the website whenever it happens.

- Cache In Trash Out Event - Large gatherings of geocachers that focus on litter clean-up, removal of invasive species, planting vegetation and trail building.
- Mega-Event Cache - Event cache that is attended by 500 or more people, often held annually.
- Giga-Event Cache - Event that is attended by 5000 or more people, usually held annually. This event can last several days.
- Wherigo Cache - Geocaches integrated with Wherigo toolset [71]. This creates a mixed reality experience while caching.
- Geocaching HQ Geocache - Visit Geocaching headquarters in Seattle, Washington. Making an appointment at least 48 hours before is required.
- GPS Adventures Maze Exhibit - Attendance at the GPS Adventures Maze Exhibit or a regional variation.
- Lab Caches - Experimental geocaches used to test new types of caches for the future. This type is really rare to find.
- Virtual Cache - Consist of discovering a location rather than a container.
- Webcam Cache - Consist of using monitor cameras on the location, get in front of the camera and save a screen capture from the website where the camera is displayed in order to log a find.
- Project A.P.E. Cache - Special caches placed in conjunction with 20th Century Fox to support the movie Planet of the Apes.
- 10 Years! Event Cache - Special event Cache for events held April 30 - May 3, 2010. Used to celebrate 10 years of geocaching.



Figure 4.1: Traditional cache, hidden at Texas A&M

- Locationless (Reverse) Cache - Consist of locating a specific object and log its coordinates. Now, these became Waymarks [72].

4.3 The Mobile Application

The recent advances in mobile technology have allowed creating new tools that facilitate daily tasks. This advances allowed the development of a geocaching application for mobile devices that allows geocachers to do all the geocaching process mentioned before in a single device [73].

The app uses the Mobile's GPS sensor to track caches nearby and display them on a map, allowing the user to select one at the time and start the search. Once the player has chosen a Target cache the app displays relevant information about it, as the size of the cache, the level of difficulty and a description of the cache in order to help players to find them, these features are displayed on Figure 4.2. Another option provided by the

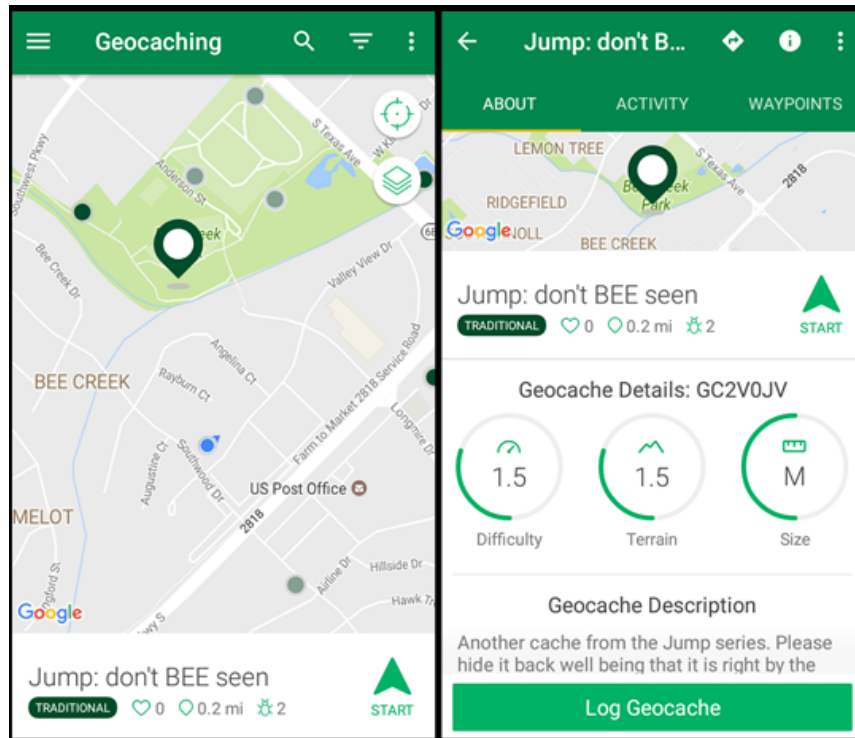


Figure 4.2: Geocaching app's interface

applications is to start the tracking module; that provides a compass in the bottom of the screen along with instructions to reach the place where the cache is located. Once the tracking function has started, the app will trace a straight line between the cache location and the position where the player is standing; the line will change along with the position of the player to reflect in the map how the player is moving. Is important to mention that, other than this line, the app does not provide any other type of directions, allowing the player to trace their own path to the cache. It does not worry about how the player manages to reach the final destination. Once the user is close to the cache's location the app vibrates and shows a pop-up dialog acknowledging the user that the cache is close. The interface also provides a compass to help players to locate the position of the cache. The app also provides the capability of uploading comments and pictures during the quest,

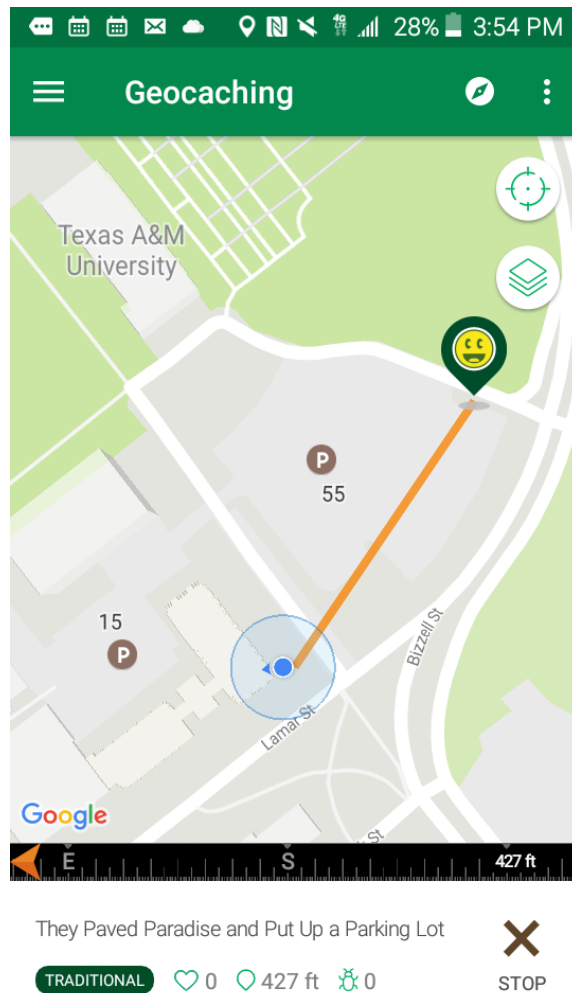


Figure 4.3: Geocaching tracking interface

fomenting online socialization between cachers, and to log and entry to inform whether they were able to find the cache or not. Using the mobile app allows cachers to delegate most of the configuration process to the mobile device at the same time [73]. The use of the mobile application has proven to be simpler and more efficient than the old method where the player has to set manually the GPS device and log into a computer in order to share and read comments.

The use of the phone while performing the search allows cachers to combine the real

world with the virtual one, creating what is called a "mixed reality" [62, 73, 6]. It is important to note that this mixed reality is not the same as AR since there is no augmentation going on during the game and the player has to change constantly between the virtual world on the phone and the real one.

4.4 Some Issues to Face

Releasing the mobile application has made an improvement on the geocachers experience [73], but the app is far from being perfect and some issues can be addressed:

1. GPS technology is not 100% accurate. This could lead cachers to follow the wrong path. It is recommended to carry a physical map as support in case the GPS sensor stops working properly [9].
2. The line system used to guide cachers is not helpful once the target location is reached. This makes the last part of the quest harder since cachers cannot rely on the app anymore.
3. Mobile applications distract attention from surroundings [74, 50, 49]. While geocachers are looking at the mobile screen, they lose awareness of their surroundings being a potential cause of accidents while cachers are distracted.
4. The comment section becomes harder to review as the number of comments increases. Scrolling is considered a tedious task [75, 76, 77].

5. ARCACHING

This section will describe the details of ARCAching and is divided into four subsections. After giving a general overview of the application, the chapter will talk first about the system architecture, then it will describe the user interface, and finally it will explain the functionality of the app and the best way to use it.

5.1 Application Overview

ARCAching is an AR mobile application proposed as a solution to all Geocaching issues mentioned before. This application allows the user to receive directions and clues about a selected geocache, and display them in the mobile device's screen overlapping camera information in order to simplify the task of searching. The application has the capability to track the user position using the mobile's GPS and help to navigate to the target geocache. This application also includes a module that allows users to input and share their own markers and clues (similarly to the comment section that Geocaching provides) so other users can visualize this information in their devices too. This way, cachers do not have to get distracted or lose awareness of their environment while looking at the phone for directions. At the same time, they reduce the time and effort they invest into reviewing and posting comments since not scrolling is required to perform those actions.

Is important to mention that, since ARCAching is still an experimental application, it does not have full support for all eighteen different types of caches that were mentioned before. At this point, ARCAching has the capability to provide full support for traditional and virtual caches mostly. However, other types of caches that are coordinate based and do not involve any sort of puzzle or the use of an external app to be found could be supported by the app at this point. Multi-Caches and event based caches are not currently supported by ARCAching.

5.2 System Architecture

In order to successfully build a system that helps users to get directions while geo-caching and share content with other users, applying a client-server architecture was required. This happens because of two reasons:

- Processing capability: Mobile devices do not have the same computational capability of a computer. Using a server will relieve the workload on the mobile devices improving the performance of the application on the phone [78].
- Allowing multiple users: The idea of the application is to allow multiple users to participate at the same time and share information. A server has to be configured in order to coordinate multiple devices and allow the sharing of information among them.

The client, that runs on mobile devices, should have the capability to search caches and comments, display directions and comments and also let users create and save new comments for others to see while searching later on. The server has to store and retrieve all information that the client sends to it. This section presents a quick description of the architecture of ARCaching system, client and server included. ARCaching client has been designed as a mobile application for Android devices [79]. There are several reasons why Android platform has been selected over other mobile operative systems, as it can be seen on the list below [80, 81, 82]:

- Android SDK is based on Java, one of the most common programming languages nowadays.
- Android is more flexible with respect to the programming environment, it does not require a special brand of computer or mobile device to be programmed and installed.

- Android SDK is retro compatible with previous versions of the operative system; therefore, a code made for the latest SDK will run fine in devices with previous versions of Android.
- It is cheaper to acquire Android devices than Apple or Windows. Is also cheaper to publish apps on Android than on the other platforms.
- Android poses a native support for Google Maps API and other Google services that will be useful for the application.

The code has been programmed on Android SDK 23 that runs on Android 6.0 "Marshmallow", the latest full release of Android OS. However, retro compatibility has been set to work with mobile devices that have Android 4.1 or greater. This will cover 95% of the devices on the market according to "Android Developer Console" information [80]. Tests were performed on a Samsung Galaxy 5 with Android 5.0 "Lollipop" since it covers all the minimum requirements for the application to run (Has an OS greater than Jelly Bean and has all the required sensors). In addition to android SDK, ARCaching also requires some extra frameworks in order to work properly. Those frameworks and a quick description of them are listed below:

- BeyondAR [61]: Open source AR browser with Geolocated object support. This framework is designed to work on Android system. Required to manage the AR interface, camera controllers and to render objects.
- Google Services [83]: Tools designed by Google to operate on Android devices. Includes Google Maps API and Google directions. These services are required to optimize the search of Caches and directions to them.
- Open-Caching API [84]: An open source version of Geocaching API. It has some restrictions and shows a limited amount of caches around the area but brings open

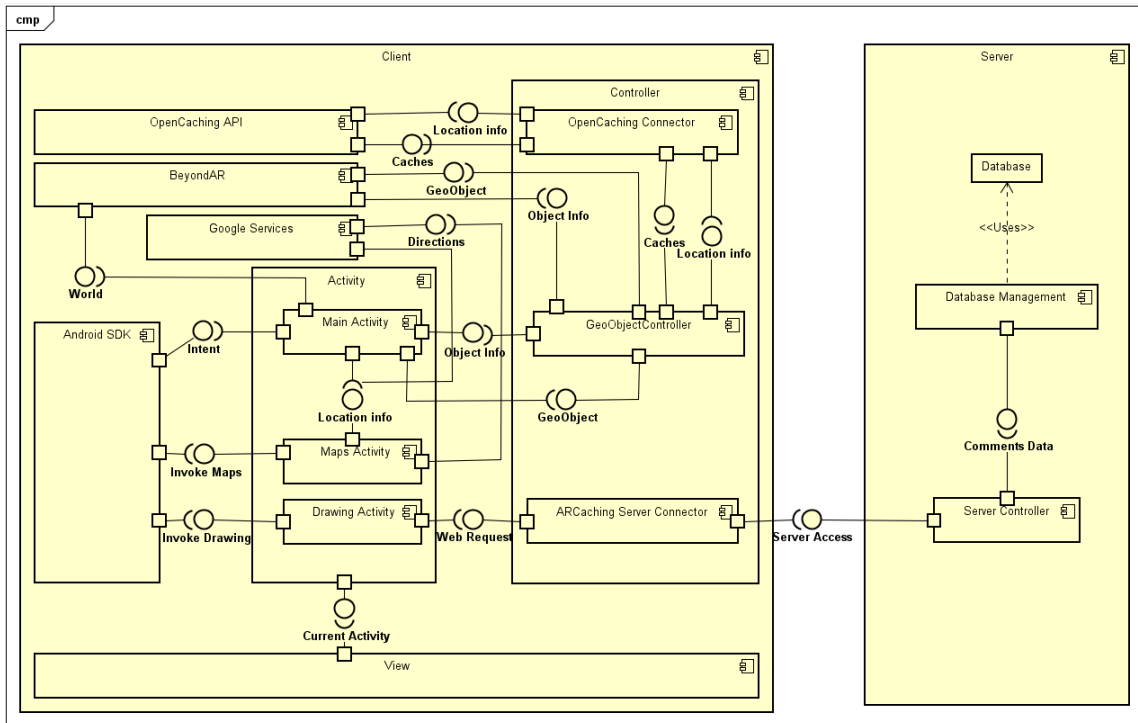


Figure 5.1: ARCaching architecture

access to anyone who requires Geocaching services. Original Geocaching API is private. Permission for use has been requested several times without response of the company.

The client architecture follows a "Model View Controller" (MVC) pattern of design [85] where views are separated from the handlers. There are three different android activities, each of them controls one main task on the application and is linked to one specific user interface.

1. **Main Activity:** This activity controls the display of camera and AR information. Has a direct link to BeyondAR framework in order to manage the world and objects displayed.
2. **Maps Activity:** Controls the selection of the Target and the interface with Google

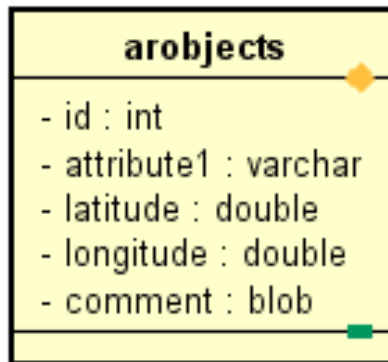


Figure 5.2: Database table content

Maps and Google Directions.

3. Drawing Activity: Controls the creation and upload of new comments.

Connection to different servers are managed by different controllers, each of one has the responsibility of establishing communication with one framework or server. Figure 5.1 shows this relationships with more detail. For ARcaching server consists of a PHP 7.0.15 web service that provides basic capabilities for searching, adding and modifying content on a database. The system uses a MySQL 5.7 database to store information about the comments and their respective route. Storage and information of caches and GPS directions are provided by OpenCaching and Google Services servers, therefore, is not required to add this information on the database. The client has the capability to retrieve information for the three previous mentioned servers and combine them in order to work properly. Because of this reason, the database on the server contains only one table to store comments. Each record contains information regarding the location, content of the comment and the id of the cache that this comment belongs to. Structure of the table is described on Figure 5.2. Communication between client and server is based on REST [86] protocol and the information exchanged is encoded using JSON format since it has proven to be faster and more efficient than XML format for information transfers [87].

5.3 User Interface

As it was mentioned before, ARCaching user interface is composed of three different screens, each of one has one specific functionality and is controlled by a specific Android activity. On this section, each of the screens and their functionality will be described.

5.3.1 Main Screen

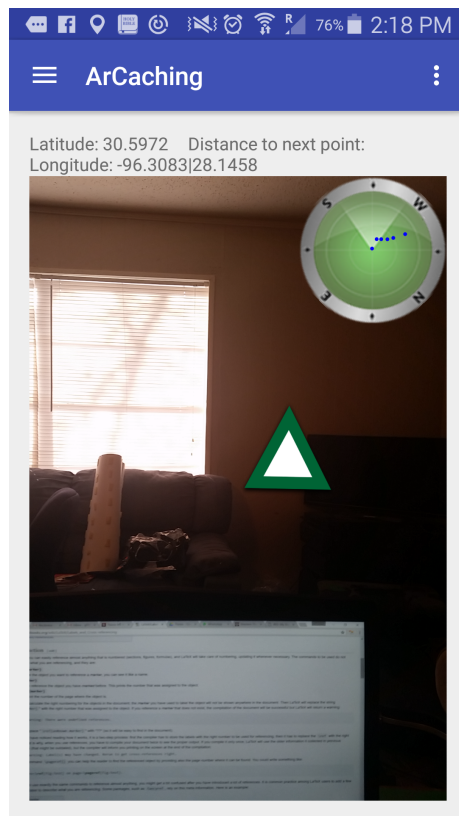


Figure 5.3: Main screen interface

This is the first screen that will be visible for the cacher whenever the app is open. As Figure 5.3 shows, most of the interface is filled by the camera section, while displays information gathered in real time with the camera at the center of the screen. On this

section is also possible to see one rendered marker overlapping the information of the camera, these markers represent the instructions that will guide players to the cache. The letters and numbers on the top display the current location of the cacher on latitude and longitude values and the distance in meters to the target marker. On the top right corner, a radar with a compass is located, this shows where the markers are located around the cacher represented by blue dots, making easier to find them and aim to them with the phone camera. Finally, the blue bar at the very top provides access to the sidebar menu as Android's standard establishes.

5.3.2 Maps Screen

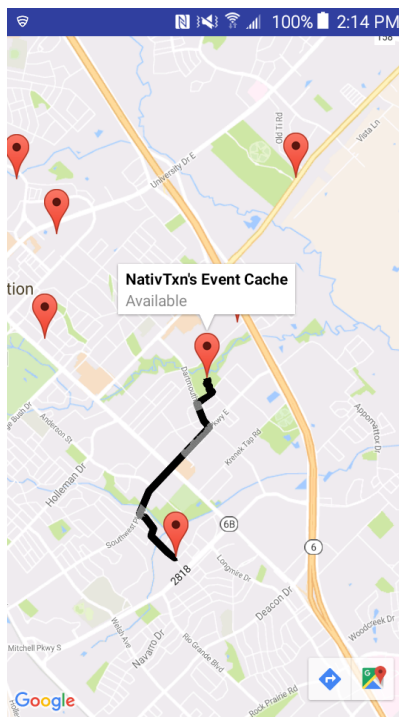


Figure 5.4: Maps screen interface

Figure 5.4 shows the maps activity screen. This screen displays caches nearby the

user's location and give the affordance of selecting one that will be chased. Since this screen and activity are direct implementation of Google Maps API [88, 89] it provides the basic capabilities that Google Maps application presents to users, these are:

- Scrolling up, down and sideways to displace the map
- Zooming up and down
- Select markers

When a marker is selected, the information regarding the selected cache appears as a text globe over it. Also, the screen displays the route that will be followed by the cacher while is using the application. Route displayed is directly pulled from Google servers by using Google directions API [90]. Users are able to go back to the main screen once a cache has been selected or by tapping on the back button on the phone.

5.3.3 Drawing Screen

The last screen on ARCCaching is called Drawing Screen and is displayed on Figure 5.5. This screen is used to create and post comments that will be displayed to other players whenever they look for the same cache. The view provides the user the following capabilities:

- Drawing/Erasing - Depending on the selected option, swiping on the canvas will either leave a mark of ink or delete it.
- Change brush size - When changing from brush to eraser or back, the system will display the option to select the size of the tool.
- Change the ink color - The application provides some options for changing the color in case the user wants to add detail con the comments.



Figure 5.5: Drawing screen interface

- New from scratch - User can start a comment from scratch by clicking the icon of "new drawing".
- Save/Comment - Saves the drawing and send it to ARCaching server. Once the comment is saved it will be visible to other players.

The interface will change back to the main screen once the user has saved and posted successfully the comment or if the back button of the phone is pressed. This last option will not save the previous work so if the drawing option is selected again the user will have to start again from scratch.

5.4 Functionality

Now that the architecture and interface of ARCaching have been described, is time to explain how the application can be used in order to have a successful experience while

Geocaching with it. This section will explain in some detail how to properly use the app.

5.4.1 Selecting a Cache

When the ARcaching application is started there is no information of the target cache or route to follow. Therefore, the first step in order to successfully use the application for Geocaching is to select the target cache. In order to achieve that, the user must follow the next steps:

1. Verify that the current location is displayed on the top section of the screen. This means that the GPS has detected the cacher's current location.
2. On the side bar select the Map view option to display the Maps View.
3. Tap on the current location marker to start the search of nearby caches.
4. Once nearby caches are displayed, tap on one to show some information about it.
5. Tap a second time on the selected cache in order to select it. Selected cache information will be sent to the main activity and the application will change automatically to the main screen.

Once the application is back on the main the position of the markers should appear on the radar and at least the first one should appear overlapping the camera information on the screen. These same steps can be followed to change the target cache if a previous cache was selected but cachers do not want to keep chasing it anymore.

5.4.2 Finding a Cache

Before starting the chase of caches it is important to verify that the Wi-Fi sensor of the mobile device is deactivated. This is because sometimes the mobile tries to triangulate the location of the user with the Wi-Fi sensor to be more accurate, but since the app works on

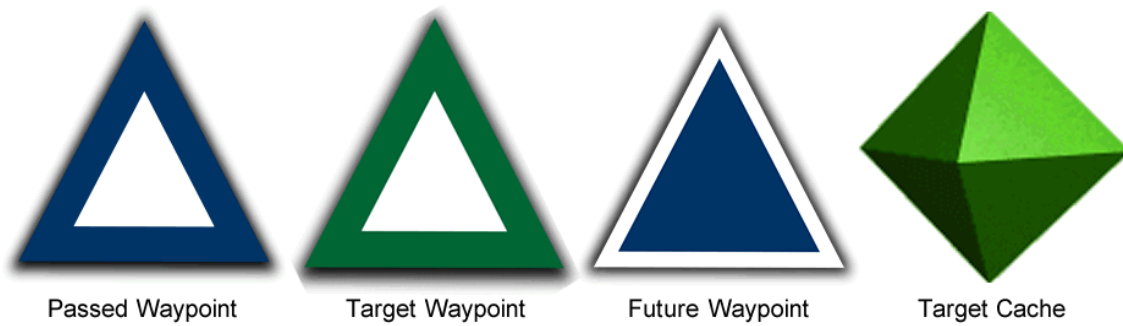


Figure 5.6: Marker's meanings

outdoors environments the Wi-Fi signal is not strong enough to help and it ends messing around with the app.

The process to find caches is very intuitive. Cachers just have to follow the markers that appear on the screen until they reach the cache location. Each marker has a specific image rendered depending on what it represents. The different renders and their meaning are displayed on Figure 5.6.

Target waypoint is always represented by a green triangle while all other future waypoints have a white triangle with a blue center. Once the target point is reached by the cacher its image changes to a blue triangle, that represents passed waypoints, and the next future waypoint on the list becomes the new target waypoint changing its image into a green triangle. The last symbol, that looks like a green box, represents the location of the target cache. It will be placed over the coordinates where the cache is physically located. Once the cachers reach this symbol they can start looking for the physical cache. Another possible type image that can be rendered over the camera information is the comments. The content and number of the comments that are displayed may vary depending on the amount of comments made by other cachers and what they decided to share on them, but they will appear as black floating images with a message written or drawn on it. Figure 5.7 displays an example of a comment.

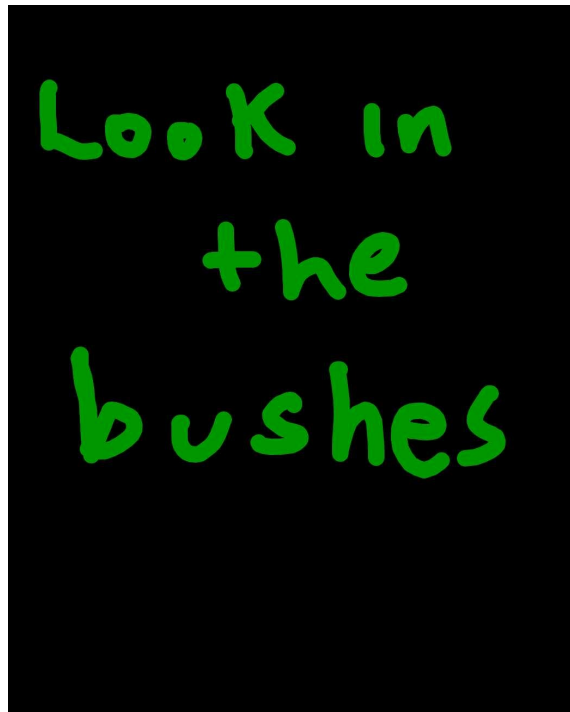


Figure 5.7: Comment

As a way to provide feedback to players, the size of the rendered images changes in inverse proportion to the distance between them and the location represented by the image. Therefore,aa images look bigger the closer the players get to them and smaller as the player walks farther. As another way of giving feedback to cachers and also as a help to locate the cache, the app starts vibrating once the player gets close to the cache. This vibration also intensifies in inverse proportion to the distance between cachers and the target.

5.4.3 Making a Comment

Similarly to the original application, players are provided with the option of making and posting comments during the quest. As a requirement for the access to the comment section, cachers need to have already selected a target cache and a route to follow. This allows the system to create a relationship between the comments and the target cache, and

display only the comments that are relevant to the selected quest avoiding overhead on the system. The process to post a comment is simple, players just have to follow the steps written bellow:

1. Select Drawing View on the sidebar, this will display the drawing screen.
2. On the drawing screen, use the tools provided on the activity to write or draw the desired comment.
3. Once the comment is ready, press the saving button. this will automatically send the information to ARCaching server.

The comment will be displayed now at the same location where it was created and it will be visible to any other player that is searching for the same cache that the target one when the comment was created. This way, cachers are allowed to help each other and socialize through the app.

These are the basic functionalities that ARCaching presents to users. The application is not really complex and is pretty intuitive to use. However, since this is still an experimental version of the app, the affordances it presents and the information displayed are still limited in comparison to the original application.

6. STUDY DESCRIPTION

The purpose of the user study presented on this paper was to determine whether or not the implementation of AR technology for geocaching purposes could improve the geocacher experience, and how does this inclusion affect the geocaching experience overall. In order to do that, ARcaching and the original geocaching application had to be tested and compared. The following section describes with some detail how the user study was designed and performed.

6.1 What to Measure

Since the purpose of the study is determine differences between both apps, the first step in designing the study was to determine what features where should be compared and what kind of metrics where be used in order to measure this differences. The research questions established four different features that had to be compared, those were:

- Time expended on finding the cache.
- Effort required to find the cache.
- Experience while commenting and reading comments.
- General experience of the application. This includes usability of the application.

Having those features selected, how each of them would be measured, and how the results of this measurements could be compared between the applications had to be determined.

6.1.1 Metrics

Time is a quantitative variable that can be easily measured and compared by timing how long it takes for the cacher to find the geocache. Effort can be considered a quantitative variable even when is not as easy to measure as time. It is difficult to measure this

feature since there is not a specific metric used to determine how much effort is invested in a certain task. However, the number of steps given by the user from the beginning of the task until the cache is found can reflect the effort invested by the user while searching the cache. Therefore, a reduced number of steps could reflect less walking around and less effort while looking for the cache. In order to be compared, these metrics had to be normalized by measuring the time and number of steps that it took for the user to walk 20Ft and dividing the total time and steps expended to find the cache by those values.

Experience with the application has to be considered a qualitative variable since there is no way to measure with numbers. However, impressions and thoughts about both applications can be collected by interviewing the participants after the study is over. The guide followed during the semi-structured interview can be found on Appendix A. Another metric useful to determine the experience that participants had on each application is the usability. Usability can be measured using the "system usability scale [91]. The survey required to perform the system usability scale can be found on Appendix B. Having the usability scale method allowed to make quantitative calculations and help to compare the experience that participants had during the study.

6.2 Data Collection Methodology

The methods used to collect data from users were simple. They were asked to search for caches using each of the applications. Time and number of steps were measured while the search was being performed. For the convenience of location, this study was performed on campus near the location of the lab since it has several caches located at walkable distances and also has a considerable number of potential participants among professors and students. After measuring the average walking time and distance of the geocaches that surrounds the laboratory, two were selected for the study. Figure 6.1 displays the location of the caches, represented by the smiley face, and the laboratory, represented by the green

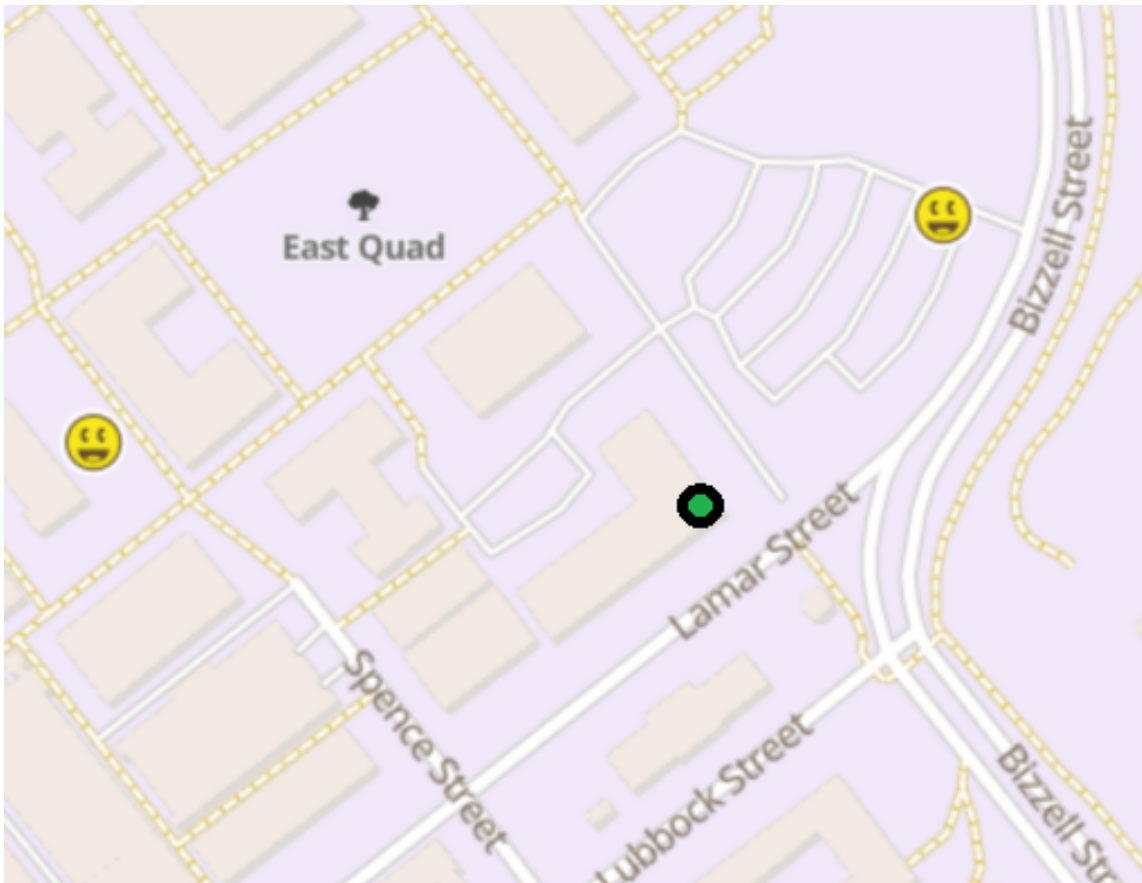


Figure 6.1: Caches selected

circle.

Before the study began, it was required to take the time and number of steps values that were used to normalize the measurements. Each participant was provided with a pedometer device and was asked to walk a 20 ft distance. Time was tracked and the number of steps counted.

After getting the parameters required for normalization, the study was divided into two tasks and one interview at the end of them. It is important to mention that, in order to avoid bias on data, the order of the tasks were not always the same. The tasks are described next:

1. Caching with the original application.

- (a) Each participant was be provided with a mobile device with the original geocaching application open. The functionality of the application and other relevant features were briefly explained to each participant. each participant was allowed to ask any questions regarding the mobile application before preceding to the next step of the task.
- (b) Each participant was assigned one of the preselected caches as a target and was asked to use the app for tracking and finding it.
 - i. The timer started to run once each participant started the search in order to record how much time it took to find the cache.
 - ii. Observation notes were taken while each participant performed the search.
 - iii. The number of steps taken by each participant while searching was counted using a pedometer device.
 - iv. Each participant was allowed to review the comments section during the search and add any comment if desired.
- (c) Once the user found the cache the timer stopped running and the number of steps marked on the pedometer device was recorded. Each participant was asked to add a comment on the application for the cache.

2. Caching with ARCaching.

- (a) Each participant was be provided with a mobile device with the ARCaching application open. The functionality of the application and other relevant features were briefly explained to each participant. Each participant was allowed to ask any questions regarding the mobile application before preceding to the next step of the task.
- (b) Each participant was assigned one of the preselected caches as a target and was

asked to use the app for tracking and finding it.

- i. The timer started to run once each participant started the search in order to record how much time it took to find the cache.
 - ii. Observation notes were taken while each participant performed the search.
 - iii. The number of steps given by each participant while searching was counted using a pedometer device.
 - iv. Each participant was allowed to review comments made by other participants and add any comment if desired.
- (c) Once the user found the cache the timer stopped running and the number of steps marked on the pedometer device was recorded. Each participant was asked to add a comment on the application for the cache.

3. Semi-structured interview

- (a) Participants were guided back to the laboratory and asked to participate in a semi-structured interview. The interview was divided into two phases.
- i. Participant was interviewed following the guide presented on Appendix A. These questions were just an incentive to start a conversation; therefore, the interview could follow different paths according to the opportunities presented. The duration of the interview was variable but never longer than ten minutes. Also, notes were taken during the interview regarding the comments and feedback provided by all participants. Answers were kept confidential and no pictures, audio or video were recorded during this process.
 - ii. At the end of the interview, each participant was provided with two copies of the system usability scale survey [91] presented on the Appendix B.

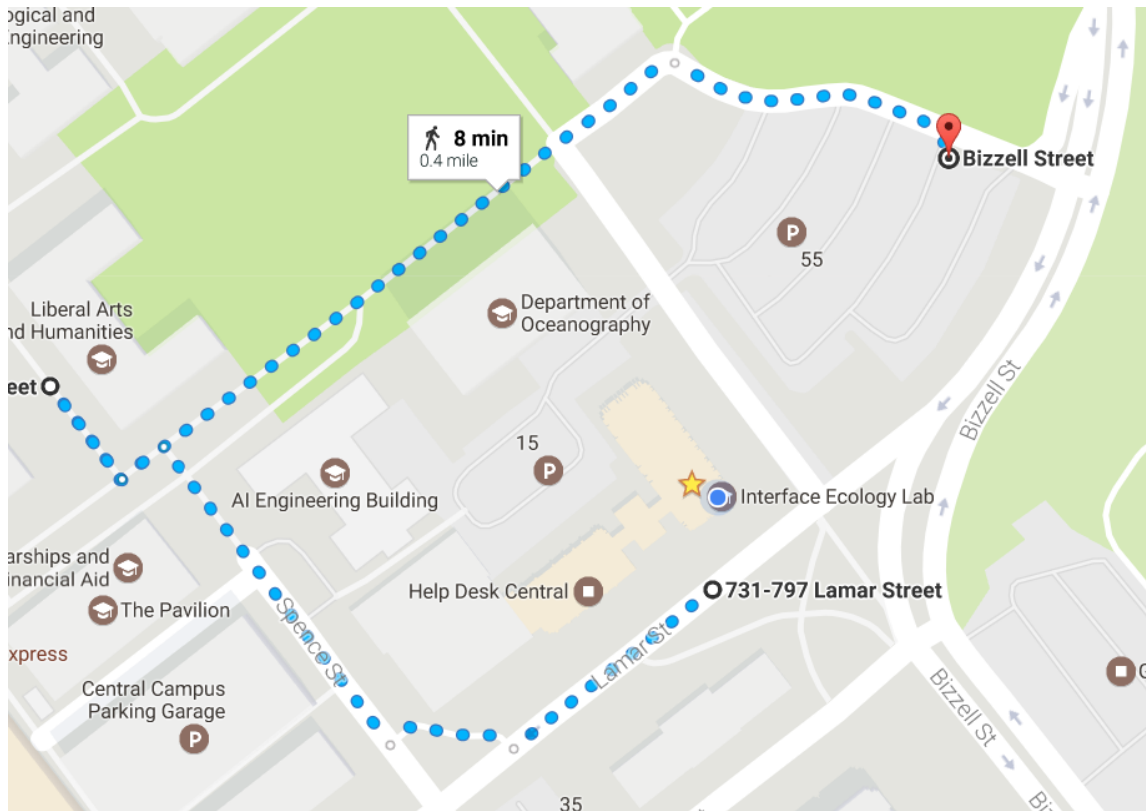


Figure 6.2: Route to caches suggested by Google Maps

Each participant was asked to fill one copy for each application.

Figure 6.2 displays the suggested route that participants followed in order to find the caches. The whole route took an average of eight minutes to walk, four minutes were required to perform each walk from starting point to the cache, and from cache to cache.

The study ended once the participant filled both copies of the form. A minimum of twenty participants was required in order to get enough data to analyze.

6.3 Evaluation Methodology

There are three quantitative variables that require being analyzed by statistic methods to determine if the difference between the applications is significant or not. The categories

that require this statistical analysis are:

- Normalized time. This value was obtained by dividing the searching time in seconds into the number of seconds it took for each participant to walk 20 feet of distance.
- Normalized number of steps as a measurement of effort. It could be obtained by dividing the total number of steps given on the search by the number of steps given on a 20 feet distance walk.
- Score on the system usability scale [91] as a measurement of the experience appreciation that the user had.

Many different methodologies could be applied to analyze the data gathered. In order to make a good decision and select the right methodology, it was required to acknowledge the purpose of the study and the characteristics that the data distribution presented. After reviewing those characteristics and compare them against many possible methods, three different test were selected to perform the data analysis and compare the methodology, those will be described and explained on the following subsections.

6.3.1 F-Test for Standard Deviation

The first step selected in order to analyze the data was to determine whether or not exist a statistical difference between the standard deviation of both samples. This step is important since it determines which path should be taken on the second test. A simple F-Test was selected to verify the existence of this difference since it has proven to be accurate enough and is simple to perform [92].

Performing the F-Test is really simple, it just requires to divide the greater standard deviation into the smaller one in order to get the F-Value. The F-Value has to be compared against the table displayed on Figure 6.3. A value bigger than the displayed on the table means the difference between the standard deviation is significant. The only assumption

d12/dn	1	2	3	4	5	6	7	8	9	10	12	15	20
1	39.86346	49.50000	53.59324	55.83296	57.24008	58.20442	58.90595	59.43898	59.85759	60.19498	60.70521	61.22034	61.74029
2	8.52632	9.00000	9.16179	9.24342	9.29263	9.32553	9.34908	9.36677	9.38054	9.39157	9.40813	9.42471	9.44131
3	5.53832	5.46238	5.39077	5.34264	5.30916	5.28473	5.26619	5.25167	5.24000	5.23041	5.21562	5.20031	5.18448
4	4.54477	4.32456	4.19086	4.10725	4.05058	4.00975	3.97897	3.95494	3.93567	3.91988	3.89553	3.87036	3.84434
5	4.06042	3.77972	3.61948	3.52020	3.45298	3.40451	3.36790	3.33928	3.31628	3.29740	3.26824	3.23801	3.20665
6	3.77595	3.46330	3.28876	3.18076	3.10751	3.05455	3.01446	2.98304	2.95774	2.93693	2.90472	2.87122	2.83634
7	3.58943	3.25744	3.07407	2.96053	2.88334	2.82739	2.78493	2.75158	2.72468	2.70251	2.66811	2.63223	2.59473
8	3.45792	3.11312	2.92380	2.80643	2.72645	2.66833	2.62413	2.58935	2.56124	2.53804	2.50196	2.46422	2.42464
9	3.36030	3.00645	2.81286	2.69268	2.61061	2.55086	2.50531	2.46941	2.44034	2.41632	2.37888	2.33962	2.29832
10	3.28502	2.92447	2.72767	2.60534	2.52164	2.46058	2.41397	2.37715	2.34731	2.32260	2.28405	2.24351	2.20074
11	3.22520	2.85951	2.66023	2.53619	2.45118	2.38907	2.34157	2.30400	2.27350	2.24823	2.20873	2.16709	2.12305
12	3.17655	2.80680	2.60552	2.48010	2.39402	2.33102	2.28278	2.24457	2.21352	2.18776	2.14744	2.10485	2.05968
13	3.13621	2.76317	2.56027	2.43371	2.34672	2.28298	2.23410	2.19535	2.16382	2.13763	2.09659	2.05316	2.00698
14	3.10221	2.72647	2.52222	2.39469	2.30694	2.24256	2.19313	2.15390	2.12195	2.09540	2.05371	2.00953	1.96245
15	3.07319	2.69517	2.48979	2.36143	2.27302	2.20808	2.15818	2.11853	2.08621	2.05932	2.01707	1.97222	1.92431
16	3.04811	2.66817	2.46181	2.33274	2.24376	2.17833	2.12800	2.08798	2.05533	2.02815	1.98539	1.93992	1.89127
17	3.02623	2.64464	2.43743	2.30775	2.21825	2.15239	2.10169	2.06134	2.02839	2.00094	1.95772	1.91169	1.86236
18	3.00698	2.62395	2.41601	2.28577	2.19583	2.12958	2.07854	2.03789	2.00467	1.97698	1.93334	1.88681	1.83685
19	2.98990	2.60561	2.39702	2.26630	2.17596	2.10936	2.05802	2.01710	1.98364	1.95573	1.91170	1.86471	1.81416
20	2.97465	2.58925	2.38009	2.24893	2.15823	2.09132	2.03970	1.99853	1.96485	1.93674	1.89236	1.84494	1.79384

Figure 6.3: F-Table alpha=0.05

that is required to validate this test is that both samples come from a normal distribution, a fact that can be easily verified by making sure the kurtosis value of the samples remains within the range of -2 and 2 [93, 94].

6.3.2 T-Test vs Mann-Whitney U Test

The existence of a significant difference in the standard deviation of both samples is important since it determines whether a T-Test is applied to analyze the data or not.

Based on a mean comparison, the T-Test is normally used to identify significant differ-

ences between two samples [95]. The test is based on the following equation:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{X_1X_2} \cdot \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (6.1)$$

Where:

$$S_{X_1X_2} = \sqrt{\frac{(n_1 - 1)S_{X_1}^2 + (n_2 - 1)S_{X_2}^2}{n_1 + n_2 - 2}} \quad (6.2)$$

The test is really simple to perform, however, the results of this test can not be taken as true unless these two assumptions can be proven:

- The size of both samples should be the same
- The variance of both samples has to be statistically similar

Therefore, if the F-Test shows that there is a difference in the standard deviation of both samples, the results given by the T-Test can not be taken as true.

As an alternative of the T-Test, the Mann-Whitney U Test is a median based test [96, 97, 98, 99, 100] that relies on the following equation:

$$U = n_1n_2 + \frac{n_2(n_2 + 1)}{2} - \sum_{i=n_1+1}^{n_2} R_i \quad (6.3)$$

Where U is the value of Mann-Whitney test n_1 and n_2 represent the size of their respective sample and R_{n_i} represents the rank of of the sample size.

The test combines the two samples and sorts their values from smallest to largest, each value is ranked and the average of the ranks for each sample is calculated and compared. This value is used to run a P-Test and determine whether or not there is any significant difference between the samples.

Since this test can be applied to samples with different variance, this is the alternative selected to apply if the F-Test determines that exist a difference between the standard

deviation of the samples. Some of the reasons that motivated to select this test are listed below:

- Samples are independent of each other for all categories.
- The values of each variable can be considered either ordinal or continuous.
- The purpose of the study is to compare and determine if there is a statistically significant difference between the data collected from both applications. This purpose can be fulfilled by this study.
- The values of data are not grouped on intervals.
- Behavior of the variance cannot be proved to be equal.

6.3.3 Kolmogorov-Smirnov Test

The previously mentioned methodologies should be enough to identify if the samples are statistically different or not. However, having an extra test to corroborate the results obtained previously never hurt. Therefore, Kolmogorov-Smirnov Test has also been included on these research.

Kolmogorov-Smirnov is a non-parametrical test that evaluates and compare the maximum distance between the empirical distribution function of the samples compared [101, 102]. This empirical distribution of a sample is defined as:

$$F_n(x) = \frac{1}{n} \sum_{i=1}^n I_{[-\infty, x]}(X_i) \quad (6.4)$$

All previously mentioned studies were performed with a 95% of accuracy, this means, a 5% of error acceptance. To simplify calculation process, a statistic package was used. For this study, Statgraphics was the tool selected to perform the calculation and compare the values of the data gathered for each category [103].

6.3.4 Qualitative Data

Regarding the data qualitative data collected during the interviews, the best way to analyzing is by categorization and coding the comments and annotations and then make interpretations [104, 105, 106]. comments and annotations were divided into one of two groups depending on which app are they made about. The information was distributed into one of the following categories:

- Observed Behavior: This category includes all observations made during the study regarding the behavior of each participant and other facts that the were noticeable but not mentioned in the interviews or comments.
- Identified strengths: This category refers to all those comments that express a positive or comfortable experience provided by the app.
- Identified issues: This category refers to all those comments that express a negative experience or discomfort produced by the app.
- Improvement suggestions: This category includes all comments that express changes, fixes or ideas that can improve ARCaching's future versions.

Comments, annotations, and answers given on the interview for both applications were considered and included into one of the previously mentioned categories. This classification helped to analyze and compare the experience of the participants during the studies.

7. EVALUATION AND RESULTS

After performing the procedures explained in the last section and gathered data from 20 users in total, this research proceeded to analyze the data. The following section will be divided into two subsections, one for quantitative data and one for qualitative data. Each subsection starts presenting the data obtained by the user study and describe the different process applied to the data analysis and the results obtained from them. Finally, this section will conclude with a discussion about those results.

7.1 Quantitative Data

This research was interested in three values that can be defined as quantitative. Those were the normalized time, normalized count of steps and the usability score. Table 7.1 presents a compilation of these values related to each one of the 20 users. The average and standard deviation of each category are shown at the bottom of the table. the data displayed have been divided in the three metrics that were tracked on the user study according to the plan presented on the previous section. Each section on the table displays the data gathered separated by each of the applications used to get it. The following part of this section has been designated to describe the process and results of applying the selected methodologies on the data collected. This part has been divided into three subsections, one per each of the categories described on Table 7.1.

7.1.1 Normalized Steps

The first category that was compared is the normalized number of steps. The value was obtained by dividing the total number of steps given by the participant while searching the cache between the number of steps given on 20 feet. Both samples have 20 entries each, making the sample size equal and allowing to proceed with the methodology. Values ob-

Table 7.1: User data

User	Norm Step		Norm Time		Usability Score	
	Geo	AR	Geo	AR	Geo	AR
user 1	36.714	82.571	33.898	115.496	50	80
user 2	82.714	78.571	70.997	83.526	47.5	85
user 3	84.857	63.285	102.702	95.01	70	92.5
user 4	79.714	61	96.75	74.25	85	75
user 5	110.625	67.875	134.14	71.145	50	90
user 6	95.714	64.142	99	62.6	50	67.5
user 7	146.714	77.7142	164.123	113.195	52.5	75
user 8	95.333	70.5	116.256	86.699	67.5	80
user 9	96	64.833	127.049	71.584	75	82.5
user 10	102.8	69.8	1.426	1.13	80	95
user 11	86	57.285	82.846	58.479	77.5	87.5
user 12	61	65.666	165.289	99.724	77.5	97.5
user 13	72.125	53.875	84.873	80.672	70	77.5
user 14	79.125	51.5	105.139	113.918	47.5	95
user 15	38.833	48.333	72.404	127.868	85	92.5
user 16	56.285	62.857	56.66	78.528	47.5	72.5
user 17	84	60	157.407	113.425	75	75
user 18	116	62.2	129.0625	85.625	75	87.5
user 19	71	73.75	66.733	104.98	87.5	72.5
user 20	103.142	60.714	135.263	115.526	77.5	92.5
Avg	84.934	64.823	100.101	87.669	67.375	83.625
StDev	25.863	8.9187	43.0188	28.567	14.497	9.0493

tained were diverse, Figure 7.1 displays a graphic of the frequency of the values measured per each one of the mobile applications.

The data collected was plotted into Statgraphics to start the analysis, the preliminary results obtained from the system are displayed on Figure 7.2. By using this summary, is possible to verify if both samples come from a normal distribution or not. Since both values, standard skewness and standard kurtosis are within the range of -2 and 2, is possible to consider that both samples are taken from a normal distribution.

It has been proven that the samples presented have a normal distribution and also that

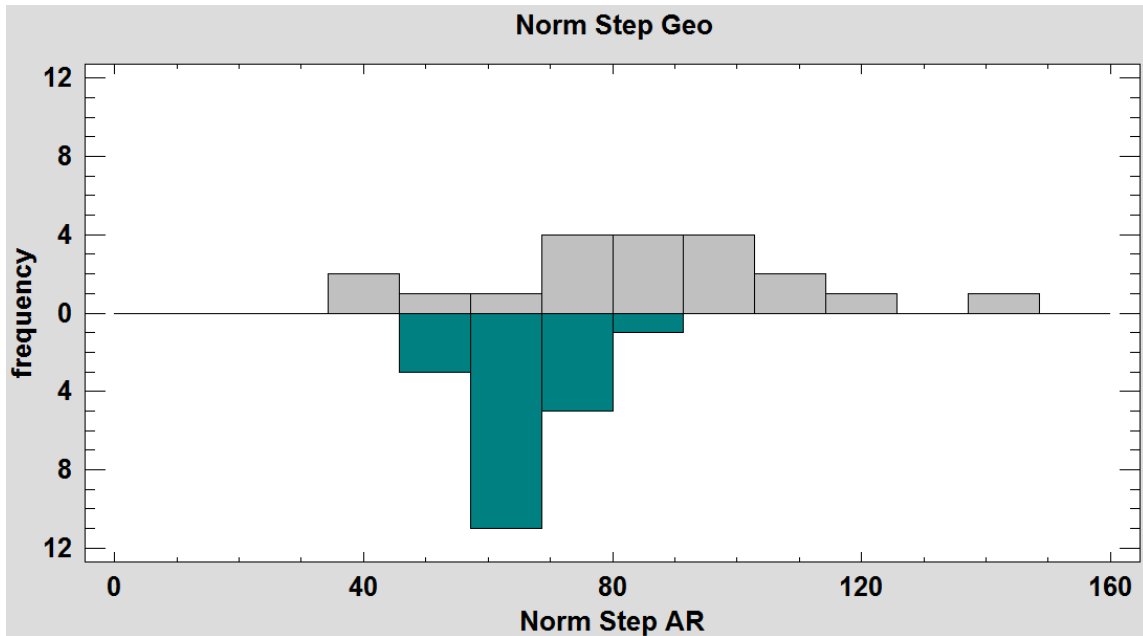


Figure 7.1: Normalized steps frequency

both samples have the same size since both samples have 20 entries. Therefore, the assumptions to proceed with the F-Test are met. The F-Test is used to identify whether the standard deviation and variance of the samples are statistically equal or not. After plotting the values on Statgraphics, the summary displayed on 7.3.

The F-Value obtained by dividing the standard deviations is 8.40951 that is greater than the value displayed on Figure 6.3 for 19 and 19 degrees of freedom ($P < 0.05$). Finally, system also generated confidence intervals for both of the samples with a 95% of accuracy. If these intervals do not overlap with each other, then it is possible to say with 95% of accuracy that the standard deviation for both samples is statistically different. The values of the intervals generated by the system were:

- Geocaching app: [19.669, 37.7757]
- ARCaching app: [6.78262, 13.0265]

	<i>Norm Step Geo</i>	<i>Norm Step AR</i>
Count	20	20
Average	84.9349	64.8238
Standard deviation	25.8636	8.91875
Coeff. of variation	30.4511%	13.7584%
Minimum	36.7143	48.3333
Maximum	146.714	82.5714
Range	110.0	34.2381
Std. skewness	0.282048	0.379092
Std. kurtosis	0.774529	-0.158323

Figure 7.2: Normalized steps analysis summary

	<i>Norm Step Geo</i>	<i>Norm Step AR</i>
Standard deviation	25.8636	8.91875
Variance	668.927	79.5441
Df	19	19

Figure 7.3: F-Test for normalized steps

Since the F-Value is greater than the value on the table, the P-Value smaller than the desired accuracy and the numbers presented on the intervals are not overlapping, is possible to say that there is significant difference between the standard deviation values. This fact makes the results of a normal T-Test unreliable and inhibits the capability of using a normal T-Test to compare the samples. Therefore, the methodology selected to compare this pair of samples is Mann-Whitney U test.

After plotting the data on Statgraphics, the system returned the medians and rank average for both samples, that are displayed on Table 7.2. After comparing the average rank of the samples, the resultant Mann-Whitney value U was 80.5 ($P < 0.05$). This value is

significantly smaller than the critical acceptance U value, 127 for this test. Therefore, is possible to conclude with a 95% of accuracy that there is a significant difference in the measurement of normalized steps for these apps.

Table 7.2: Mann-Whitney U test values for steps

	Median	Avg Rank
Geocaching app	84.4286	26.475
ARCaching app	63.7143	14.252

Finally, in order to verify the results obtained by the previous process, the Kolmogorov-Smirnov test was also applied. Using the formula presented in the previous chapter, the empirical distribution of both samples were calculated and compared. Figure 7.4 displays the quantile plot graph generated from those distributions.

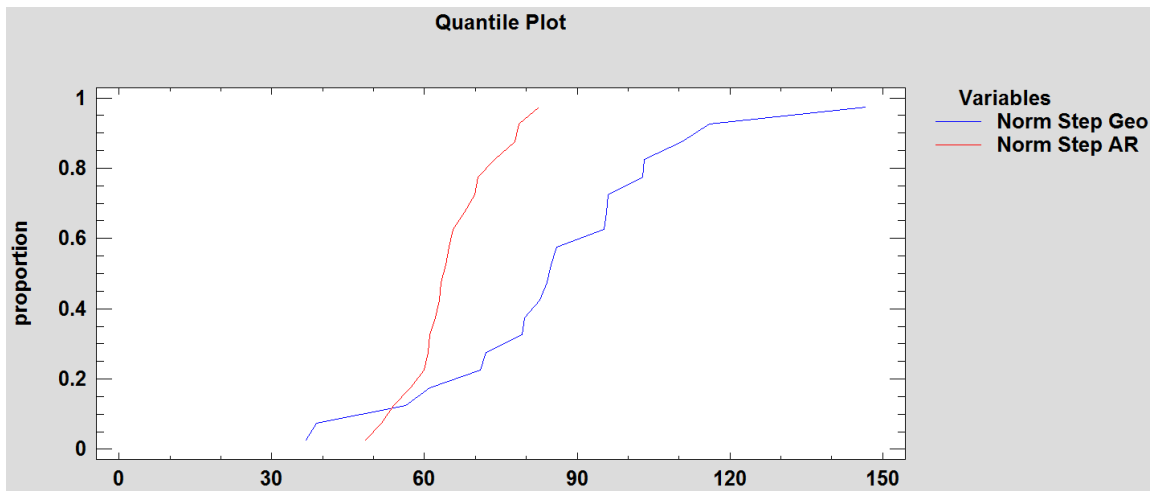


Figure 7.4: Empirical distribution quantile plot

According to Statgraphics, the maximum distance calculated for both distributions is

0.65 ($P < 0.05$). Therefore, the Kolmogorov-Smirnov Test also corroborates the significance of the difference found on the normalized number of steps for both applications.

7.1.2 Normalized Time

The same procedure had to be applied in order to test the existence of significant difference on the values gathered for the normalized time. The value of normalized time was obtained by dividing the total time consumed in finding the cache by the time it took to walk 20 feet. Time was measured in seconds. Similarly to the measurements performed with the number of steps, there are two samples, one per app, and 20 different entries per each sample. Again, like in the previous subsection, the frequency of the values measured is displayed on the graph shown on Figure 7.5.

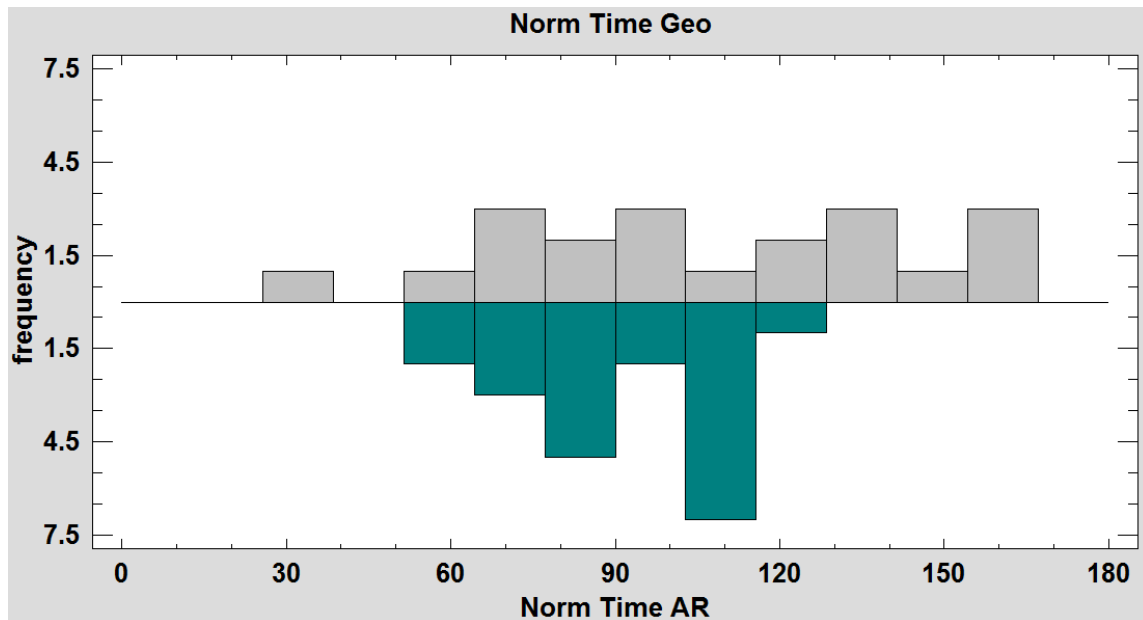


Figure 7.5: Normalized time frequency

Figure 7.6 display a summary of the computations made by Statgraphics regarding

the values of time for both applications. The figure shows the standard skewness and standard kurtosis in red, that are a prove of normality on the distribution if their value remains within -2 and 2. Is possible to notice that the values displayed for both applications remains within this range, therefore, is safe to say that both samples follow a normal distribution behavior and the results obtained for methodologies like the F-Test or the T-Test are reliable. Therefore, is possible to proceed with the F-Test in order to compare the standard deviation of the samples and look for any significant difference.

	<i>Norm Time Geo</i>	<i>Norm Time AR</i>
Count	20	20
Average	107.163	93.2644
Standard deviation	37.1623	20.5624
Coeff. of variation	34.6782%	22.0474%
Minimum	33.8983	58.4795
Maximum	165.289	127.869
Range	131.391	69.3895
Std. skewness	-0.189231	-0.0941921
Std. kurtosis	-0.699058	-1.15483

Figure 7.6: Normalized time analysis summary

In order to perform the F-Test, the data had to be typed into the system. After plotting the values for the F-Test on Statgraphics and run the procedure, the summary displayed on 7.7 was returned.

The F-Value obtained by dividing the standard deviations is 3.26631 that is greater than the value displayed on Figure 6.3 for 19 and 19 degrees of freedom ($P < 0.05$).

Finally, the system also generated confidence intervals for both of the samples with a 95% of accuracy. If these intervals do not overlap with each other, then is possible to say

	<i>Norm Time Geo</i>	<i>Norm Time AR</i>
Standard deviation	37.1623	20.5624
Variance	1381.04	422.813
Df	19	19

Figure 7.7: F-Test for normalized time

with 95% of accuracy that the standard deviation for both samples is statistically different. The values of the intervals generated by the system were:

- Geocaching app: [28.2616, 54.2783]
- ARCaching app: [15.6375, 30.0329]

Since the F-Value is greater than the value on the table, the P-Value smaller than the desired accuracy and the numbers presented on the intervals are not overlapping, is possible to say that there is a significant difference between the standard deviation values. This fact makes the results of a normal T-Test unreliable and inhibits the capability of using a normal T-Test to compare the samples. Therefore, the methodology selected to compare this pair of samples is Mann-Whitney U test.

Proceeding with the test, data was plotted into Statgraphics. As a response, the system returned the medians and rank average for both samples, that are displayed on Table 7.3. After comparing the average rank of the samples, the resultant Mann-Whitney U value was 152.0 ($P > 0.05$). On this test, the value is greater than the critical acceptance U value. Therefore, is not reliable to consider the existence of a statistical difference between this samples.

And just to corroborate the results obtained by the previous process, the Kolmogorov-Smirnov test was also applied. Using the formula presented in the previous chapter, the

Table 7.3: Mann-Whitney U test values for time

	Median	Avg Rank
Geocaching app	103.921	22.9
AR Caching app	90.855	18.1

empirical distribution of both samples were calculated and compared. Figure 7.8 displays the quantile plot graph generated from those distributions.

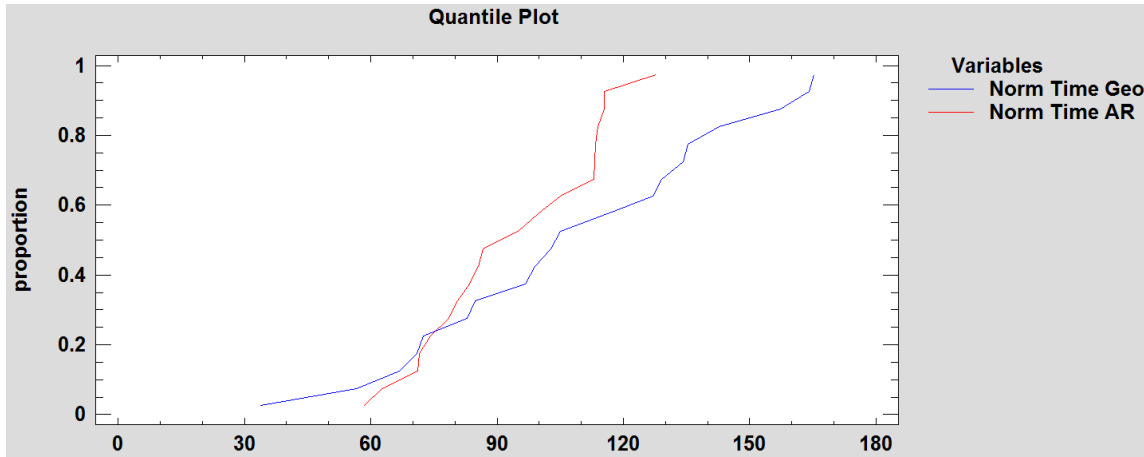


Figure 7.8: Empirical distribution quantile plot

According to Statgraphics, the maximum distance calculated for both distributions is 0.4 ($P > 0.05$). Therefore, the Kolmogorov-Smirnov Test also corroborates there is not statistical difference between the samples for the normalized amount of time taken while geocaching with both applications.

7.1.3 System Usability Score

The last category measured is the score given by the user on the System Usability Test displayed on appendix B. This test measures the usability of the system by giving a score

within 0 and 100 points. The higher the score of an application is, the more usable the tested system is at the eyes of the user. For this category also two samples were taken with 20 entries each of them. The frequency of the values is displayed on the Figure 7.9.

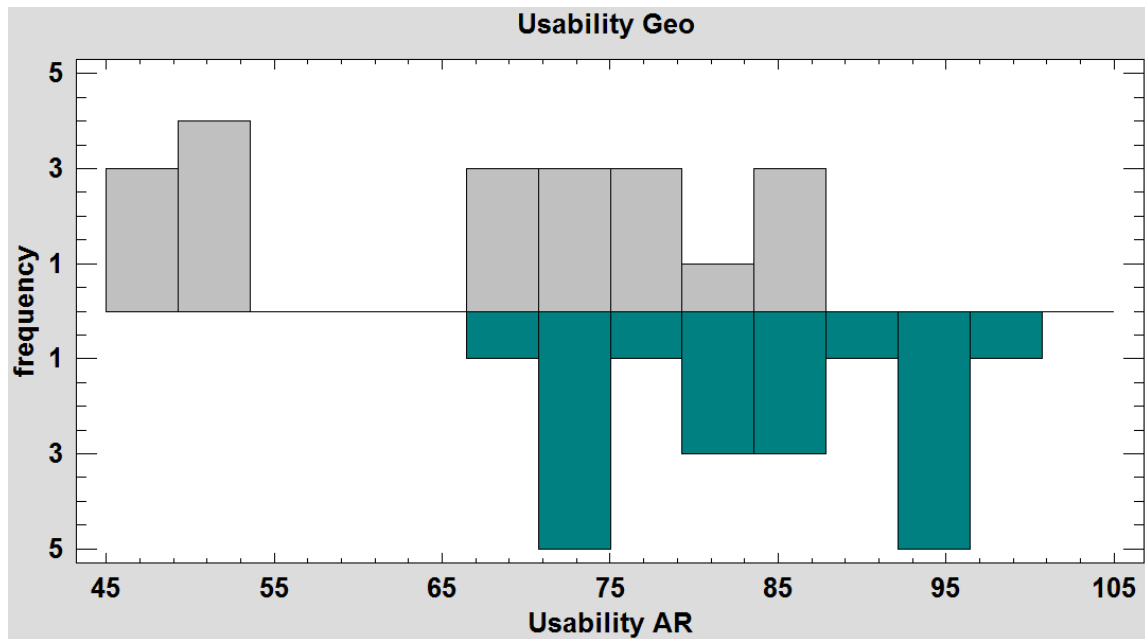


Figure 7.9: System usability score frequency

Proceeding with the study, the data collected for this category was also plotted into Statgraphics for analysis. After performing the computations, the system returns the summary displayed on Figure 7.10. The figure shows the standard skewness and standard kurtosis in red, that are a prove of normality on the distribution if their value remains within -2 and 2. Is possible to notice that the values displayed for both applications remains within this range, therefore, is safe to say that both samples follow a normal distribution behavior and the results obtained for methodologies like the F-Test or the T-Test are reliable. Therefore, is possible to proceed with the F-Test in order to compare the standard deviation of the samples and look for any significant difference.

	<i>Usability Geo</i>	<i>Usability AR</i>
Count	20	20
Average	67.375	83.625
Standard deviation	14.4976	9.04939
Coeff. of variation	21.5178%	10.8214%
Minimum	47.5	67.5
Maximum	87.5	97.5
Range	40.0	30.0
Std. skewness	-0.595203	-0.159618
Std. kurtosis	-1.41758	-1.18682

Figure 7.10: System usability score analysis summary

The next step in the analysis was to use the F-Test to determine whether or not there is a statistical difference in the standard deviation of the samples. In order to perform the F-Test, the data had to be typed into the system. After plotting the values for the F-Test on Statgraphics and running the procedure, the summary displayed on 7.11 was returned.

	<i>Usability Geo</i>	<i>Usability AR</i>
Standard deviation	14.4976	9.04939
Variance	210.181	81.8914
Df	19	19

Figure 7.11: F-Test for system usability score

The F-Value obtained by dividing the standard deviations is 2.56658 that is greater than the value displayed on Figure 6.3 for 19 and 19 degrees of freedom ($P < 0.05$).

Finally, the system also generated confidence intervals for both of the samples with a

95% of accuracy. If these intervals do not overlap with each other, then is possible to say with 95% of accuracy that the standard deviation for both samples is statistically different. The values of the intervals generated by the system were:

- Geocaching app: [11.0253, 21.1748]
- ARCCaching app: [6.88197, 13.2173]

Since the F-Value is greater than the value on the table, the P-Value smaller than the desired accuracy and the numbers presented on the intervals are not overlapping, is possible to say that there is a significant difference between the standard deviation values. This fact makes the results of a normal T-Test unreliable and inhibits the capability of using a normal T-Test to compare the samples. Therefore, the methodology selected to compare this pair of samples is Mann-Whitney U test.

Proceeding with the Mann-Whitney U test, data was plotted into Statgraphics. As a response, the system returned the medians and rank average for both samples, that are displayed on Table 7.4. After comparing the average rank of the samples, the resultant Mann-Whitney U value was 76.5 ($P < 0.05$). Therefore, is possible to conclude with a 95% of accuracy that there is a significant difference between the scores obtained on the System Usability Score for both apps.

Table 7.4: Mann-Whitney U test values for usability

	Median	Avg Rank
Geocaching app	72.5	14.325
ARCCaching app	83.75	26.675

Finally, and just to verify the results obtained by the previous process, the Kolmogorov-Smirnov test was also applied. Using the formula presented in the previous chapter, the

empirical distribution of both samples were calculated and compared. Figure 7.12 displays the quantile plot graph generated from those distributions.

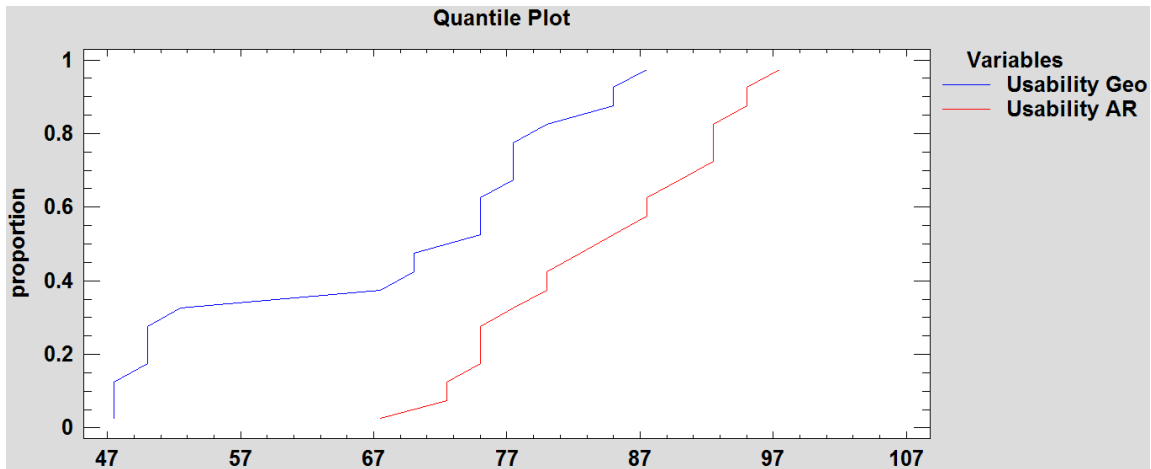


Figure 7.12: Empirical distribution quantile plot

According to Statgraphics, the maximum distance calculated for both distributions is 0.5 ($P < 0.05$). Therefore, the Kolmogorov-Smirnov Test also corroborates the significance of the difference found between the scores given by the participants to both applications on the system Usability Test.

7.2 Qualitative Data

Having all quantitative data analyzed and identified the existence of differences in the results, it is time to proceed with the analysis of the observations, comments, and answers to interview questions. This qualitative data is useful to determine the experience that participants had while geocaching with bot apps. In this subsection, the qualitative data gathered during the user studies is analyzed and classified.

Tables 7.5 and 7.6 presents a compilation of the comments, answers and observations made during the user study divided by user.

Table 7.5: Observations per user part 1

User	Geocaching	ARCaching	Both
User 1	Walked straight forward	Wandered around	No check comments Didn't leave comments
User 2	Straight line doesn't help Didn't check comments Didn't leave comments	Icons should be at ground level Add a minimap Left comment	Founded cache without problem
User 3	Straight line doesn't help Didn't check comments Didn't leave comments	Comments should display in popup dialog Checked comments Left comment	Wandered around
User 4	Easier to get to the place Tedious to use once close to the place Wandered around Didn't check comments	Helps to find in reduced places Tiring to hold the phone all the time Found easily Checked comments Change icons to color scale	combine properties of both Didn't leave comments
User 5	Feedback is confusing Wandered around Didn't check comments complicated	icons are overlapping Found easily Checked comments	Didn't leave comments
User 6	Doesn't provide enough clues Doesn't provide a route Didn't leave comments Didn't check comments Wandered around	Radar is helpful Add a minimap Left comment Checked comments Found easily	
User 7	Doesn't provide good directions Smooth and continuous walked the wrong direction Didn't check comments	It will work better on Google Glass icons get lost sometimes Change icons to color scale Checked comments	Wandered around Didn't leave comments
User 8	Wandered around	Found easily reduce number of waypoints comments are useful	Didn't leave comments Checked for comments
User 9	Wandered around Described app as weird	Found easily More visual More interactive	Didn't leave comments Checked for comments
User 10	Wandered around Hard to use	Found easily Overlapping icons are confusing	Didn't leave comments Checked for comments

After analyzing this information provided by the users, the qualitative data was classified into one of the following categories:

- **Observed Behavior:** This category includes all observations made during the study regarding the behavior of the participant and other facts that were noticeable but not mentioned in the interviews or comments.
- **Identified strengths:** This category refers to all those comments that express a positive or comfortable experience provided by the app.

Table 7.6: Observations per user part 2

User	Geocaching	ARcaching	Both
User 11	Wandered around walked the wrong direction Didn't check comments	Found easily AR helps to get oriented Checked for comments	Didn't leave comments
User 12	Gave up Hard to use	Wandered around Fun Improve graphics	Didn't leave comments Checked for comments
User 13		Vibration and notes are useful Put icons to ground level Radar is helpful	Wandered around Didn't leave comments Checked for comments
User 14	Information is overwhelming	Aim is hard	Wandered around Didn't leave comments Checked for comments
User 15	Walked straight forward	Wandered around Radar is helpful	Didn't leave comments Checked for comments
User 16	Found easily Don't like this app Didn't good directions	Found easily Radar is helpful Directions are useful Make radar bigger Checked for comments	Didn't leave comments
User 17	Gave up Hard to find once in the place	Wandered around AR useful on unfamiliar places	Didn't leave comments Checked for comments
User 18	Wandered around Not really interactive	Found easily Checked for comments	Didn't leave comments
User 19	Walked straight forward no directions	Wandered around Radar is helpful limit ability to see around implement on Google glass Vibration and notes are useful Directions are useful	Didn't leave comments Checked for comments
User 20	Wandered around confusing walked the wrong direction line is not helpful	Found easily Comments should display in popup dialog Easy to use Checked for comments	Didn't leave comments

- Identified issues: This category refers to all those comments that express a negative experience or discomfort produced by the app.
- Improvement suggestions: This category includes all comments that express changes, fixes or ideas that can improve ARcaching's future versions.

Note that at this point the interest is focused just on ARcaching since is not possible to make any change on the original application. However, the feedback given to the original

application can also be used to improve AR Caching future versions.

7.2.1 Observed Behavior

Observing and taking notes during the study provided good feedback about how the ways users interact and experience the applications, and comparing them also provides useful information regarding the experience and interaction. From the observations these are the most noticeable points to remark:

- Not many participants left comments for the others, but most of them reviewed and used them once they were available.
- None of the participants gave up on the chase using the application.
- Participants lost the markers sometimes.
- Most of the users found it easier to find the target with the app.
- Users were expecting to receive directions to the target instead of making and following their own path.
- Some users preferred to rely on the radar better than on the markers.

7.2.2 Identified Strengths

The following list contains the most remarkable comments that mention the features that the participants found useful or comfortable.

- The app is simple to use.
- The radar is really useful.
- AR is helpful to get oriented.
- Providing directions to the target is better than just pointing the location.

- Is easier to check comments on AR.
- Is easier to search the cache with AR once the player gets close to the target location.
- The app is visual and interactive.

7.2.3 Identified Issues

The following list contains the most remarkable comments that mention the features that presented problems to the participants.

- Markers overlap when they are too close.
- Is tiring to use AR all the way to get to the target place.
- Markers are missing sometimes.
- The search is not continuous or smooth, participants have to stop to find missing markers time to time.

7.2.4 Improvement Suggestions

The following list contains the most remarkable improvements or changes suggested by the participants to apply in future versions of the app.

- Display markers at ground level would reduce confusion.
- Adding a mini-map texture to the radar would make it better.
- Displaying comments in pop-up dialogs would help to reduce the overlapping.
- Reduce number of markers to fix the overlapping issue.
- Creating a hybrid app that uses a map view to get to the target place and switch to AR mode once the player is close.

- Using a color scale to rate the distance to markers would improve the feedback given by the app.
- Using better markers and graphics would improve the experience.

And with these lists, the analysis of qualitative data is completed.

8. DISCUSSION

The results obtained from the previous section provide enough information to discuss how ARcaching performed during the user studies, what were the pros of using AR for geocaching purposes, what issues the app has to face, and what kind of improvements could be applied in future versions. Also, with the information obtained is possible to determine whether or not the application of AR improved the performance and experience of the users, and whether or not is a good idea to try using AR for another kind of activities similar to Geocaching. This section is dedicated to perform discussion and present the results found during the user study.

Regarding the results obtained from comparing the normalized number of steps given while performing the cache, the test proved the existence of significant difference between the two conditions. Determining which one is greater or smaller or how much this difference is can be determined by looking closer to the data obtained during the studies.

Figure 8.1 presents a box graph comparing both samples providing a visualization showing that the values presented for ARcaching are smaller than the values obtained for the original application, presenting the idea that the AR application has the tendency to reduce the number of steps given by the participants while geocaching. Considering the fact that the study revealed a statistically significant difference in this category, and the observations described in the qualitative study describing that most of the users found easier the target with the AR app, is safe to argue that ARcaching accomplished the goal of reducing the amount of effort required to find a cache. Some comments provided by the participants during the interview also support this statement, those comments can be found on Tables 7.5 and 7.6.

The same argument cannot be made about the values obtained on both apps for the

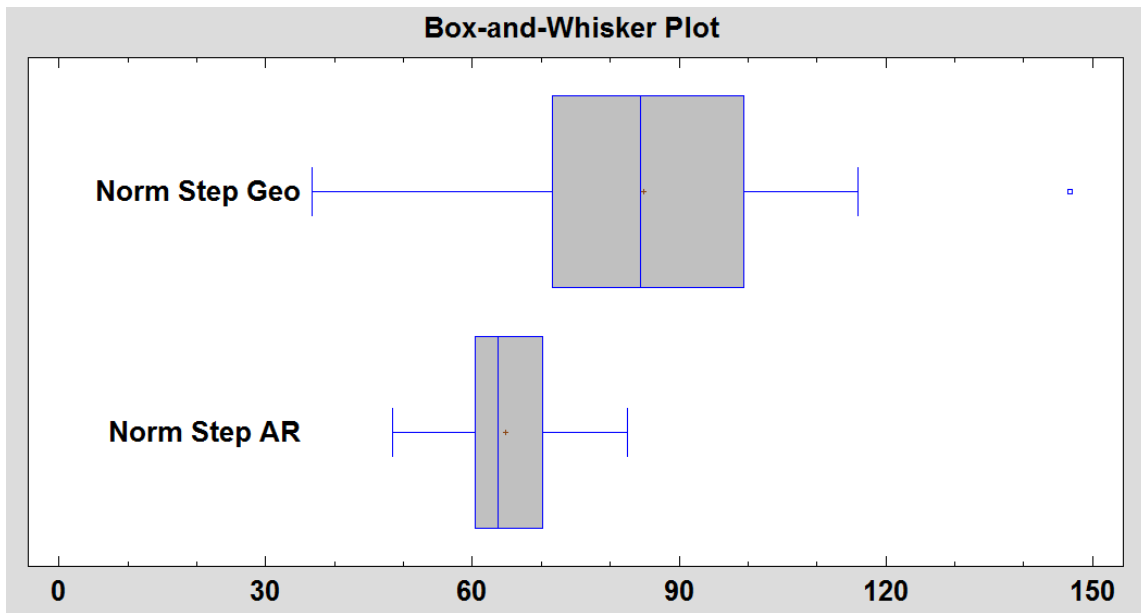


Figure 8.1: Normalized steps Box-and-Whisker plot

normalized time. Although there was a significant difference between the standard deviation and variance of the times measured, the results provided by Mann-Whitney U test and the Kolmogorov-Smirnov test does not support the existence of significant difference on the values for time. While reviewing the values listed for the normalized time on Table 7.1, it is noticeable that the values on both columns, for Geocaching and AR Caching applications, lay on similar ranges. It is also visible how the boxes overlap on the graphic presented on Figure 8.2.

The test for normalized steps showed that the number of steps required to locate the cache was reduced by the AR application, also, the observations and comments presented on the qualitative data supported this fact. Now the question is, why the amount of time did not present a difference as the effort? In order to answer this question, it is required to review again the observations and comments presented on Tables 7.5 and 7.6. Some of the observations revealed that from time to time participants lost the target marker,

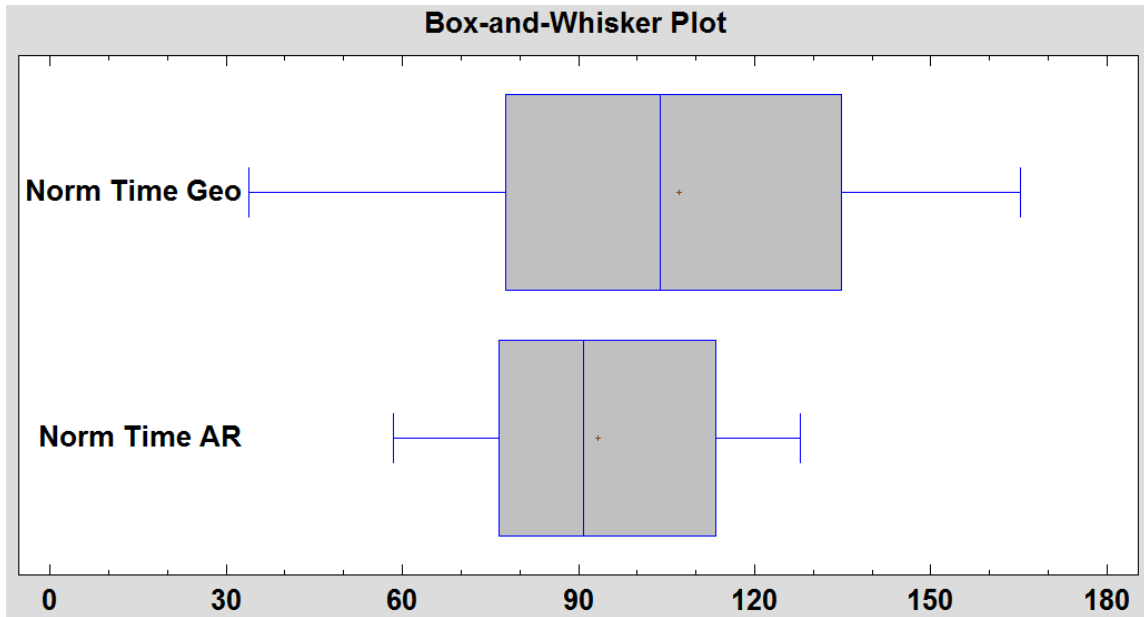


Figure 8.2: Normalized time Box-and-Whisker plot

perhaps due to GPS jumping of their own location as they walked between buildings. When this happened, they tended to stop walking and look around in place to find it again. This action does not count more steps but the time is still running, therefore, even when ARcaching helped to reduce the effort required to find the caches, it was not capable of reducing the amount of time required to find them. This issue is also mentioned on some comments made by the participants saying that markers disappeared sometimes or overlap with others making difficult to keep track of them sometimes.

The test performed for the normalized amount of steps and time have helped to answer two of the three research questions formulated for the first Hypothesis. So far we know that AR can help to reduce the effort invested on searching for the cache but it makes no difference regarding the amount of time expended. The third research question formulated for the first hypothesis was to determine how easy and useful the use of comments was. Figure 8.3 displays a graphic with the number of participants that review and left

comments per app. The observations made during the study show more users made and left comments using AR Caching than in the original application, however the number was small in both circumstances. In both apps, more users reviewed comments than left comments. Interviews with the users suggested that the comments were more accessible and useful on the AR app. In the original app the comments are static text in a list, however in the AR app the comments are virtual markers in their field of view with specific locations mapped to them. The comments made by the participants during the interviews also reveals that it was easier to access the comments and that displaying them was helpful to find the cache, even though few of them decided to left comments for future participants.

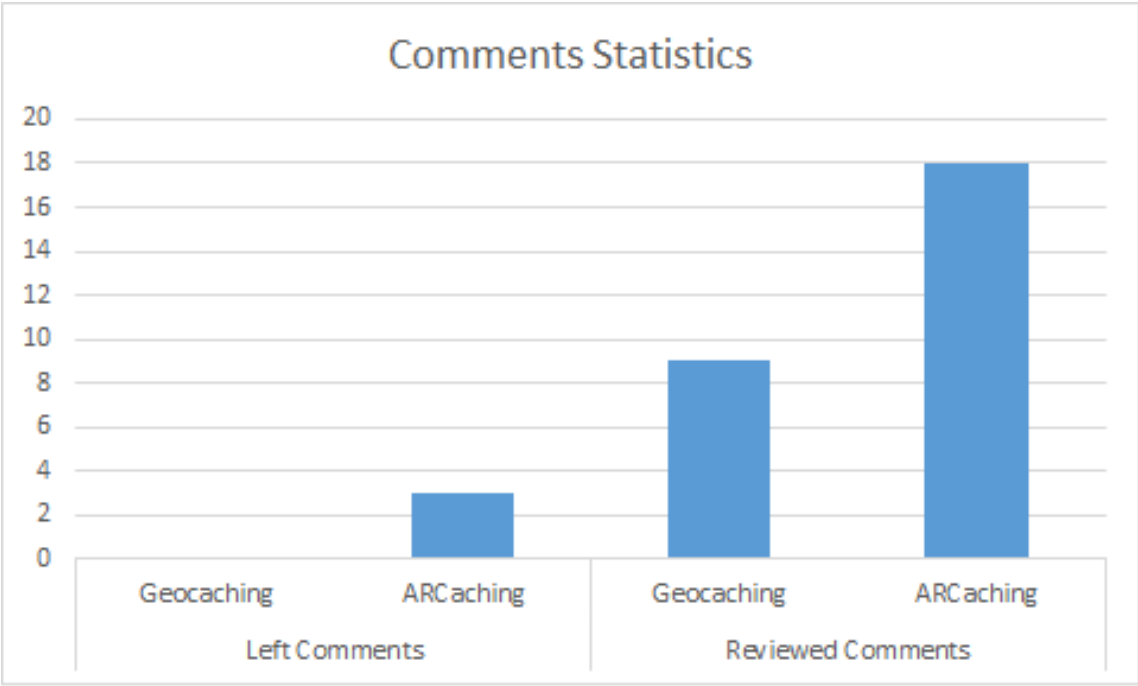


Figure 8.3: Comment statistics

The second hypothesis targeted by this research refers to the user experience while

geocaching and how it changes after applying AR to geocaching. The item selected to measure the experience was the System Usability Score, that allows participants to rate each application according to the experience they had during the study. Figure 8.4 displays the rates of scores obtained from the participants on the usability test. It is visible that AR Caching has been ranked better than the original Geocaching app. It is true that there is part of the graphic that shows overlapping, however, the statistical tests performed on the previous sections proved the existence of significant difference between the two samples.

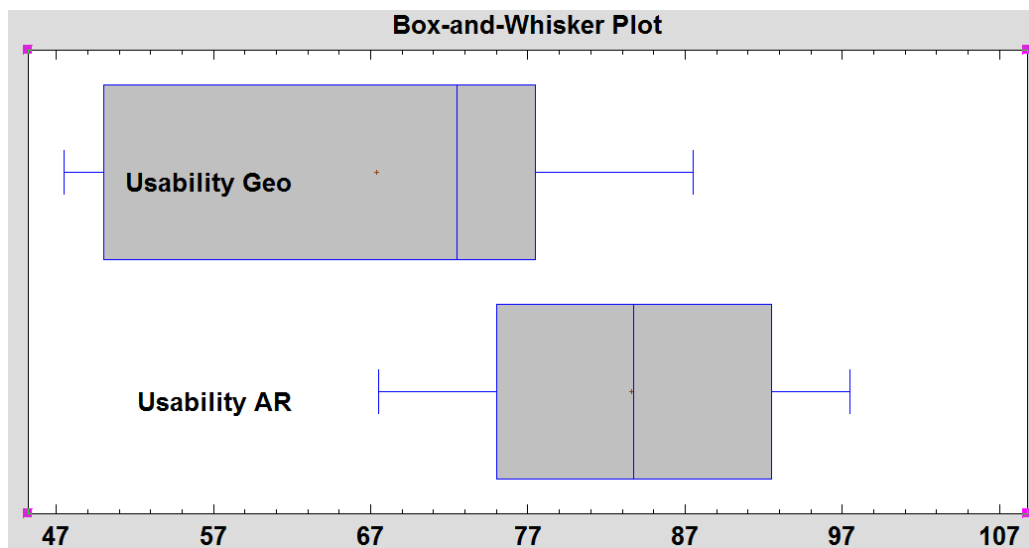


Figure 8.4: System usability score Box-and-Whisker plot

Comparing those results obtained on the statistical test with the graphic gives the idea that users preferred the use of the AR application than the original one. The comments provided by them at the interviews also support this idea, mentioning that they found it easier to search for the cache or follow directions with the AR app, and described it as fun, visual and helpful. All these facts support the idea that using AR for geocaching purposes can improve the experience have by cachers during their quest.

9. CONCLUSION

AR Caching was built as an alternative to the original Geocaching app. AR Caching implements AR to aid cachers on their quest while looking for geocaches. In order to measure the performance and user experience provided by the AR application, a comparative user study was designed and performed measuring these features against the original Geocaching app. 20 participants were asked to search for caches using both apps (alternating and randomizing the order). The users' time to find the cache, number of steps taken, and comments left and reviewed were recorded. Additionally, qualitative interview data and observations were recorded. The users also evaluated the usability of both systems. From the data collected during the study and the comments made by the participants, it was possible to conclude the following statements:

- Using an AR mobile application for Geocaching application successfully reduced the number of steps required to search and find caches (implying that they took a more direct route).
- The use of an AR mobile application for Geocaching had no effect on the amount of time expended while searching the caches (most probably due to GPS jumping and users waiting for the device to realign).
- Using AR to present user's comments on Geocaching encourages more user to review them (but not necessarily the creation of them).
- Using an AR mobile application for Geocaching purposes improved the user experience of geocachers.

Despite the fact that the inclusion of AR into geocaching is not perfect and there was issues

that still need to be fixed, the results obtained by this research promise a brilliant future for mixing this technology with geocaching and many other applications similar to it.

10. FUTURE WORK

There are multiple ways this work can be improved through future work. This section is dedicated to list and describe some of those improvements that should be considered to change, add or implement on the next versions of the app or new apps based on this research.

Some of the issues were found during the user study. These include issues observed and also mentioned by the participants. The most commonly mentioned issue by the participants is that the waypoint markers should be made clearer. Some suggestions mentioned were to lower the position of the markers to ground level and to beautify the appearance of the icons. A color scale on the icons to provide feedback regarding the distance would also help the users to better understand the directions given by the app. It has also been considered to change the 2D rendered icons for 3D models since a 3D object can blend better with the world and make the mixture of virtual and real objects smoother. By fixing the confusion produced by the markers, the game could become continuous and smooth and prevent the users from losing the markers occasionally through their walk; it also might help to reduce the time spent Geocaching, but that will have to be tested in future studies.

The overlapping of markers that were too close to each other was also a concern mentioned many times by participants. Some ways to fix this issue are reducing the number of markers displayed at any one time or allow more space between markers. Having all comments displayed at once also contributes to a bit of a mess around the cach. One approach could be to reduce the overload caused by comments is to use a single comment icon to indicate the existence of one, and display the comment on a pop-up window or sidebar once clicked. Reducing the size of the markers may also fix this issue, however, this reduction could also increase the loss of markers while walking and lead to more confusion.

Another change that may improve future versions of the application is upgrading the radar by adding a map as background. Many participants mentioned that the inclusion of a mini-map or modifying the radar to work like a mini-map would help more, especially since the radar became a critical tool helping participants to find markers when they got lost. One suggestion from participants that were to create a hybrid app, a combination of the original and the AR applications, that guides the user to the place where the cache is hidden using a normal map interface and switch to AR mode once the user gets close enough to start the search. This is an interesting approach that may actually present really good results and should be considered to test in future studies. Comparing the performance of a hybrid app against the original one and also against a pure AR app could lead to discovering new ways to apply AR.

It also exists the possibility of combining the AR application with wearable devices to improve the user experience. So far, two different wearable devices have been considered to be part of the future versions of this application. The first wearable considered, and also mentioned during the user studies, is Google glass [44]. Displaying the markers directly to the eye would help to reduce the effort invested for the users while holding the phone. The second wearable considered is the haptic vest [48], that would provide additional feedback for users while geocaching. Haptics has shown to be effective for providing navigational feedback to walkers [49], paratroopers [48], motorcyclists [50], and physical therapy patients [107], as the skin is capable of differentiating a large amount of sensory input with low cognitive overhead [108, 109]. Both wearable devices combined with the current application would provide a very different experience and it would be interesting to make studies and identify which combination of them could produce better results and a better experience for cachers.

Regarding the comment section, not many participants decided to leave comments for other users. This issue could be produced because the comment section was not visible to

them since it was on different activities and the access was located on the sidebar. Future versions of ARCaching should consider making this option more visible for users, making it noticeable, and encouraging users to share clues and enhance the experience for future players. One option considered but not implemented on this research because fell out of the scope was to add a gesture recognition module that overlaps the camera information and allows users to create quick predefined comments on the same screen. It would be interesting to test this approach on future versions of the app since the code is ready for this inclusion. Another option that might help to make the comment section visible is to change the location of the button that opens the drawing activity from the sidebar to the main screen. There is white space used now to display the current location that could be easily removed and changed for this button. This change would not present an issue since most of the participants did not even notice the use of this white space.

One last final improvement to consider for future versions is the inclusion of more geocaching types to support. Right now the app only supports traditional and virtual caches but there is a big list of different types of caches. Including more caches will provide more possibilities of game experience to cachers. It would be interesting to see how the experience of ARCaching changes with the different type of targets, but again, this question will have to wait for future studies.

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APPENDIX A

INTERVIEW GUIDE

As the last activity of this study I will ask you some questions regarding your experience during the activities.

1. How would you describe your experience searching for the cache while using the 1st mobile application?
2. What do you think was useful from the app?
3. What would you change in order to make it better?
4. How would you describe your experience searching for the cache while using the 2nd mobile application?
5. What do you think was useful from the app?
6. What would you change in order to make it better?
7. If you want to make any comment or observation, please feel free to do it.

Thanks for your time and help.

APPENDIX B

SYSTEM USABILITY SCALE REPRINTED FROM: [91]

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	Strongly disagree					Strongly agree
1. I think that I would like to use this system frequently	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
2. I found the system unnecessarily complex	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
3. I thought the system was easy to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
4. I think that I would need the support of a technical person to be able to use this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
5. I found the various functions in this system were well integrated	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
6. I thought there was too much inconsistency in this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
7. I would imagine that most people would learn to use this system very quickly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
8. I found the system very cumbersome to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
9. I felt very confident using the system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
10. I needed to learn a lot of things before I could get going with this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	