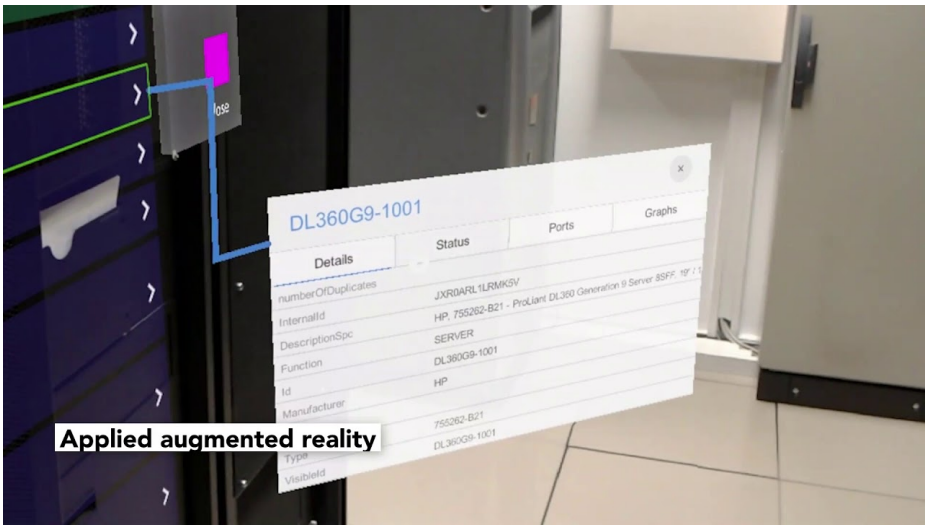
UM-SJTU Joint Institute
Major Design Experience
(Ve450)

VMware#1 - AR in Data Centers
Design Review 1 Report

Sponsor: Gavin Lu, VMware
Mentor: Yixing Jia, VMware
Instructor: Mingjian Li, UMJI



An example of AR software used in data center [1]

Group 21

Shuyi Zhou	Email: zhoushuyi_sue@sjtu.edu.cn
Chenyun Tao	Email: tcy1999@sjtu.edu.cn
Liying Han	Email: hanliying_17@sjtu.edu.cn
Yaxin Chen	Email: leepace666666@sjtu.edu.cn
Jinglei Xie	Email: xie_jinglei@sjtu.edu.cn

October 19, 2020

[1] www.youtube.com/watch?v=1Pe028PjQhs

Contents

1 Abstract

Maintenance and audits are necessary in data centers, and thus people have developed various computer systems to assist on-site maintenance and auditing work. However, most of the systems are not integrated together, and lack user-friendly instructions and information access.

To improve the efficiency of on-site maintenance and audit work, it is necessary to solve this problem, which is also the aim of our project. In order to solve the problem, we can divide our project into a back end part which is an integrated data system and a front end part which provides a user interface to display the information vividly. In our project, we use the software system Flowgate developed by Vmware as the back end database, and augmented reality (AR) for the front end application.

The customer requirements of our project include short reaction time, information correctness, comfortable display, and portable device. By conducting literature search and considering the constraints in reality, we further set up the engineering specifications based on the requirements. We quantify the object localization time, barcode identification time, database query time, AR image generation time, object localization accuracy, data retrieval accuracy, smooth display, appropriate temperature, platform, light, and small package size.

To help us complete the project, we divide it into several tasks and set milestones. The next milestones are to achieve an app that is able to output the corresponding information based on server's ID, as well as to process the AR part. Before design review three, we want to finish the integration of the two parts and complete a prototype which fulfills the basic functions. After then, we may improve our product by developing better user interface, dealing with multiple bar codes simultaneously, and making it multi-platform.

The outcome of our project should be an app that could obtain all kinds of information related to a specific data center from the back end database Flowgate, and display necessary information using AR to aid data center maintenance and audit work. Then, by using this app to apply AR in data centers, we could facilitate data center maintenance and audit work.

2 Problem Description and Introduction

We are Group 21 of Capstone Design Fall 2020 from University of Michigan - Shanghai Jiao Tong University Joint Institute. The title of our project is **AR in Data Center**, sponsored by VMware, Inc. As the name implies, the project is about applying augmented reality (AR) to work related with data centers. In this report, we will provide necessary background and introduction to the project, literature review on existing designs, customer requirements, engineering specifications and project plan.

For this section, the background of our project will be presented, the problems and needs will be formally defined, the strategy will be generally discussed, and the expected outcome will be stated.

2.1 Background Overview

A Data Center (DC) is a major infrastructure and facility which contains a high quantity of servers and computers to provide internet services for many companies in the world (such as Google, Amazon, etc.) [1]. It usually requires high-level reliability and availability. In many DCs, various kinds of critical components keep running all time, and any interruption in its services may cause major problems. Thus, we need both regular and emergent DC maintenance to make sure that computers, servers, cooling systems, and many other critical devices are working properly. If any error happens, fast recovery should be conducted. In addition, regular auditing work is also necessary for DCs to ensure that every component or device is properly placed and used, which is labor consuming as well.

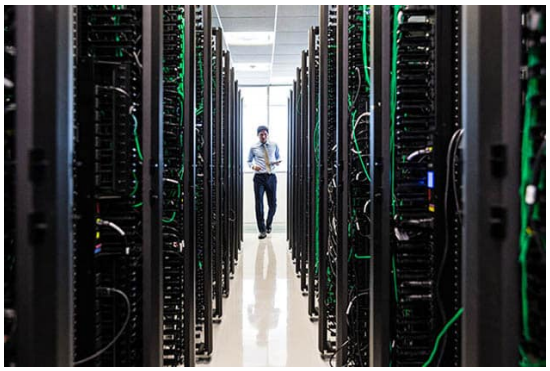


Figure 1: A typical data center (DC) (cisco.com)

To aid DC maintenance and audits, people in the industry have already developed some kinds of computer systems. For example, Data Center Infrastructure Management (DCIM) can monitor, check, control and manage the energy usage of IT devices in a DC [1]; Configuration Management Data Base (CMDB) contains all relevant information about the components of the information system and the relationships between those components [2]. Some more intelligent systems can even detect component failures and provide possible repairing strategies. Still, in many situations, we need human workers to fix the problem manually inside DCs, as well as to conduct on-site audits.

2.2 Problems and Needs

As mentioned in the previous section, we do have various computer systems to contain necessary information for on-site maintenance and auditing work. However, these systems are usually not integrated together, which means if we want to access different kinds of information (eg. data from environment sensors, power usage information, device models and parameters, etc.), we have to visit different systems to fetch the data, which could be a complex work.

Another problem is that on-site workers in DCs usually do not have user-friendly enough instructions and information access. Sometimes they have to face very tedious literal descriptions in manuals or documents, and sometimes they need to search information manually in different data systems. That could greatly reduce the efficiency of maintenance and audit work. Thus the two main problems for many current DC maintenance and audit work can be summarized as

- Lack of integrated information system;
- Lack of user-friendly instructions and information access.

To solve the above two problems, what we need are

- An integrated system that involves all the information together;
- A more user-friendly tool to aid and instruct on-site maintenance and audit work.

With the above improvements, the efficiency of on-site maintenance and audit work can be greatly improved.

2.3 General Strategy

To realize the needs, we can divide our project into two parts: the back end part and the front end part. For the back end part, we can establish an integrated data system to contain and provide all necessary information of the data center. For the front end part, we need to develop a user interface to display the information in a vivid way. More details are given in the following sections.

2.3.1 Back End Implementation

For the back end of the project, we already have different systems to contain different kinds of data, such as DCIM and CMDB mentioned previously. Also, VMware has developed a software system called *Flowgate* [3] to integrate the existing systems together and provide convenient access to all types of data (Figure 2). Thus we can use Flowgate as our back end database, and make use of API to fetch data from it.

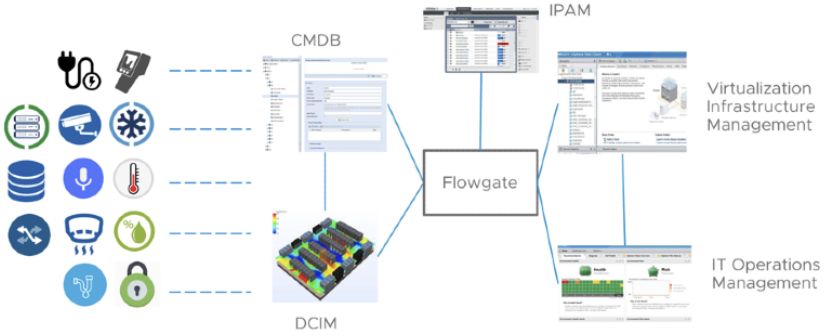


Figure 2: Flowgate: a system to integrate various kinds of data systems for data centers

2.3.2 Front End Implementation

For the front-end application, we are going to use augmented reality, *AR*, which is a combination of information generated by computers and real-world scenarios. The three basic hardware components of AR are sensors, processors and displays [4], all of which could be contained in a smart phone. For software developers, there are some open source software development kits such as Google ARCore and ARKit. Almost all the AR toolkits support common operating systems like iOS and Android, so we can easily develop apps in these platforms.

An example of the usage of AR is shown in Figure 3, which is a function in Google Map. The App can label information onto real-world scenes to provide visual guide to its user.

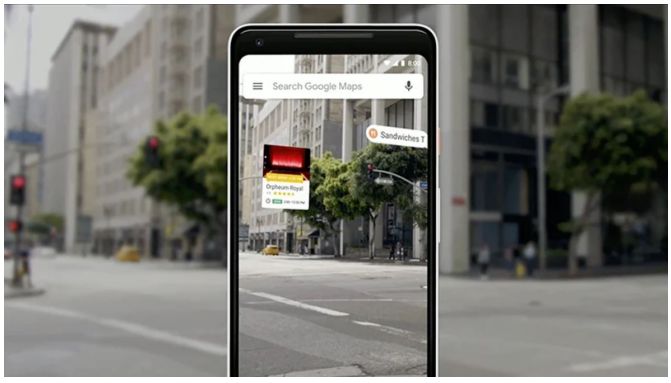


Figure 3: AR in Google Map

If we use AR to aid DC maintenance and audit work, we can obtain information visually and easily, avoiding unnecessary visits to different data systems. Also, AR can provide instructions in a convenient and vivid way, which is more user-friendly for the on-site technicians.

2.4 Expected Outcome

The product of our project is expected to be an AR App which can obtain all kinds of information related to a specific data center from the back end database (Flowgate), and display necessary information and instructions in a real-time manner (using AR) to aid data center maintenance and audit work. More intuitively, the product could be similar to Figure 4.

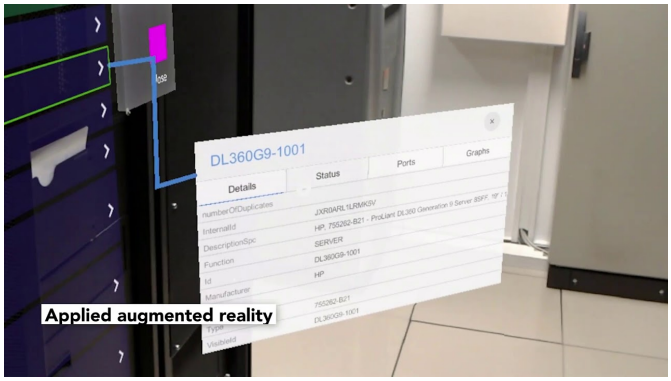


Figure 4: An example of AR software used in data center [2]

Also, the App is expected to have quick reaction time, relatively low power consumption and high compatibility to different types or versions of operating systems. More details about design specifications can be found in section 4.

3 Literature Reviews and Benchmarks

In order to have a better understanding of how to solve the problem, we have conducted several literature reviews on related technology. This can also help us meet customer requirements, and find out our novel solution on this project.

3.1 Literature Search Methods

Search by Keywords Augmented Reality, Data center maintenance, Flowgate, Data Center Visualization, Collaborative AR, AR in Data Center

Search on Platforms Google Scholar, SJTU Digital Library, U-Mich Digital Library, IEEE Digital Library, Github

3.2 Competitive and Related Products

3.2.1 Augmented Assembly using a Mobile Phone [5]

This is a mobile phone based augmented reality (AR) assembly system. It is based on a client-server architecture, where complex model information is stored on a PC, and a mobile phone with the camera is used as a client device to access this information. With this system, users are able to see an AR view that provides step by step guidance for a real world assembly task.

[2] www.youtube.com/watch?v=1Pe028PjQhs

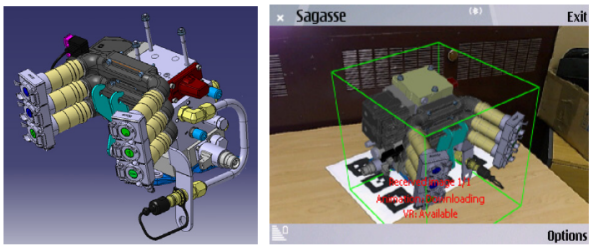


Figure 5: An example of CAD model and AR view of a hydraulic tractor.

This system is made up of two parts: a PC server software and a visualization/controller client on a smart phone. The phone client software takes images of the real assembly site, and sends them to the PC server. After the PC server receives the image, it will compute the AR model that matches the image, and send it back to the phone. The user then sees the augmented views of real world assembly tasks on the phone. The transmission of data between PC and mobile phone is realized by WLAN or Bluetooth.

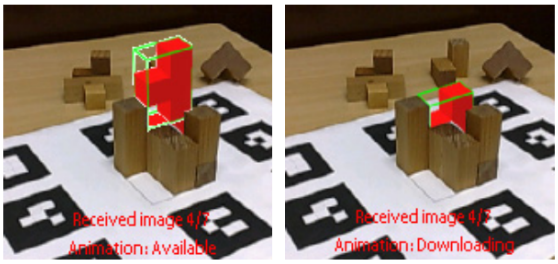


Figure 6: Augmented assembly of a 3D puzzle on a mobile phone.

To be more illustrative and intuitive, the augmented view is provided as an animated image, so that the step by step guide for assembly can be provided.

Advantages This system does not need to use many computing resources for AR on mobile phones, as the computation part is performed on the PC server.

Disadvantages The data transmission time between the phone and PC server is long. The average time to send and receive an image is 19.13 seconds over Bluetooth and 3.44 seconds over WLAN. Also, this system does not involve database of real-time information, so it is hard to be implemented on database.

3.2.2 Mobile augmented reality in the data center [6]

This is the product invented by IBM that can be used to help manage data base. It enables system administrators to easily identify various hardware assets in data center, and provides them with an additional tool to interact with those assets. Users scan QR code on the rack to fetch data from the Tivoli MEO server, which stores information of ID and location of each asset on the rack. AR on the phone marks the outline of each asset by showing a red frame of it.

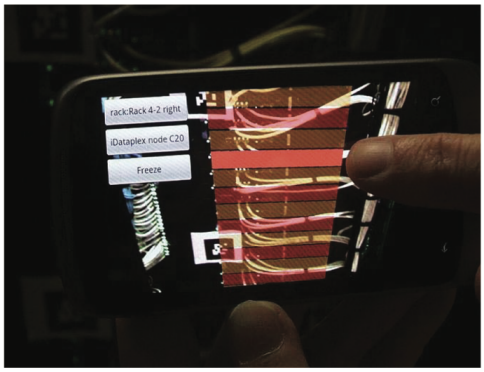


Figure 7: Visual overlay of data center assets on top of assets in an IBM iDataPlex rack.

Aside from information of ID and location, there is also a "freeze" button. Users are able to point the device at an area of interest and freeze the video capture of camera, so that they can check the device in a comfortable position. They do not need to hold the device up at an awkward angle while they are interacting with the application.

Advantages As users can freeze the camera capture, this product is user-friendly. Also, the AR visualizes the outline of each asset by red boxes.

Disadvantages There is limited information stored in Tivoli MEO server: only location, name of each machine and position where a new asset can be added. It does not check and use over physical information other than QR code, like signal lights.

4 Customer Requirements (CR) and Engineering Specifications (ES)

The benchmarks indicate that the basic requirement of our customers is to display real-time information of data center with AR, which could be divided into four detailed customer requirements. By conducting literature search and considering the constraints in reality, we further convert the requirements into engineering specifications.

4.1 Details of CR and ES

4.1.1 Short Reaction Time and the Corresponding ES

CR: Short Reaction Time

ES: Object Localization Time, Barcode Identification Time, Database Query Time, AR Image Generation Time

A research on user psychology shows that a user can get distracted in 1 second, so short reaction time is required in our project [7]. The execution steps of our application include the localization of barcode, barcode identification, database query, and the AR image generation. Therefore, we need to control the time of these tasks to fulfill the requirement of short reaction time. Based on literature search, our APP should be able to localize the barcode in 0.5s [8], identify the barcode in less than 0.05s [9], achieve an O(log(n)) complexity in the time of

database query, which depends on the data size, and take less than 0.1s to generate the AR image [10].

4.1.2 Information Correctness and the Corresponding ES

CR: Information Correctness

ES: Object Localization Accuracy, Data Retrieval Accuracy

Another important feature of our product is information correctness. In our application, the tasks related to achieving information are barcode localization and data retrival. According to state-of-art technologies, we need to realize a 90% accuracy on localizing the barcode [11] and more than 99% accuracy on retrieving data [12].

4.1.3 Comfortable Display and the Corresponding ES

CR: Comfortable Display

ES: Smooth Display, Appropriate Temperature

User experience is also essential for our project, and thus we would like to ensure a comfortable display, which is achieved by keeping a smooth display and an appropriate temperature of the devices in our application.

To realize a smooth display, we could set the frame rate above 15 frames per second [13]. The temperature of the device can keep increasing when AR is on, and thus we need to control the sensible temperature below 40 °C [14][15].

4.1.4 Portable Device and the Corresponding ES

CR: Portable Device

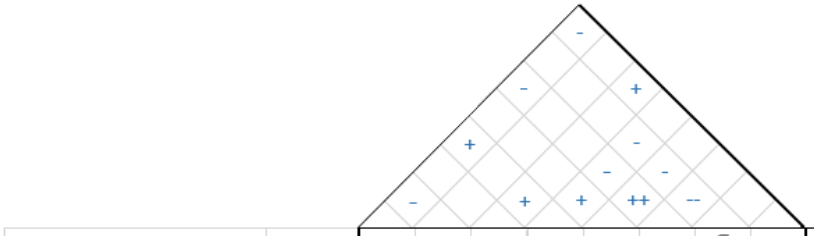
ES: Platform, Light, Small Package Size

AR application can be loaded in portable devices like smart phones or pads. Nowadays, the operation system of most of the smart phones and pads on the market is either Andriod released by Google, or iOS released by Apple. Both Google and Apple launch AR toolkits. The toolkits are available on Android 7.0 or above and iOS 11.0 or above, which limits the platforms of the portable devices where our application could run [16][17]. Our application need to scan barcodes, which will be affected by light. A recent research shows that the light condition to ensure the performance of our application should be larger than 40 lx [18].

Considering the storage capacity of portable devices, we also need to keep a small package size, with less than 110MB for Android and 940MB for iOS [19][20].

4.2 Quality Function Deployment

Based on the customer requirements and engineering specifications described above, we can evaluate our benchmarks and develop our house of quality (HOQ), which is shown in Figure 8.



++ strongly positive + medium positive - medium negative -- strongly negative Blank totally unrelated	Weights (1 - 10)	Object Localization Correctness	Object Localization Time	Barcode Identification	Database Query	AR Image Generation	Frame Rate	Device Temperature in Operation	Size of Software Package	Mobile Augmented Assembly	IBM
Short Reaction Time	6		9	3	9	3	3		1	4	5
Information Correctness	10	3			9	1		1		8	8
Comfortable Display	7	1				3	9	3	1	7	4
Portable Device	5							3	9	1	4
Measurement Units		%	s	s	s	s	fps	℃	MB		
Target Value		90	0.5	0.05	1	0.1	15	40	110		
Absolute Importance		4	9	3	18	7	12	7	11		
Relative Importance %		5.63	12.7	4.23	25.4	9.86	16.9	9.86	15.5		
Rank Order of Ecs		7	4	8	1	5	2	5	3		
Mobile Augmented Assembly											
IBM											

Figure 8: House of Quality

4.2.1 Customer Requirements and Weights

Our customers are companies that own data centers. By doing customer survey and studying our benchmarks, we conclude the customer requirements and their corresponding weights, and list them in Figure 9, which is part of our HOQ. The weights range from 0 to 10, and a larger weight means a bigger importance. The most crucial requirement of our product is information correctness, since our product will be of no use if the information it provides is incorrect. The other three requirements are related to user experience. Since portable device is the easiest to be satisfied, it has the lowest weight.

Short Reaction Time	6
Information Correctness	10
Comfortable Display	7
Portable Device	5

Figure 9: Customer Requirements and Weights

4.2.2 Benchmark Competitions against CR

The information correctness of both Mobile Augmented Assembly product and the IBM product is high, as the correctness of data is the most important factor to solve database maintenance problem. Mobile Augmented Assembly product is not portable, as it needs a nearby computer server. The animated way of AR display is good, but the reaction time is not short. IBM product only has one phone client, so it is portable. The AR display and reaction time is fair. See Figure: 10

Mobile Augmented Assembly	IBM
4	5
8	8
7	4
1	4

Figure 10: Benchmark Competitions against CR

4.2.3 Generate ES and Cross Correlate ES

The details of generating ES from CR are described in Section 4.1. Their cross correlations are shown in Figure 11. A "++" symbol shows there is a strong positive correlation between the two engineering specifications, while a "–" symbol shows there is a strong negative correlation; a "+" or "-" symbol means there is a weak correlation.

The object localization correctness has weak correlations with some specifications. One is object localization time. If we want to achieve a larger localization accuracy, then the time needed to localize it will be increased. Besides, a larger localization accuracy means we need a better localization model, which can result to a larger software package size. The device temperature also has weak correlations with some several specifications. If frame rate is increased or AR image generation time is reduced, then the device temperature will probably increase. The only strong correlation exists between AR image generation time and the frame rate; if AR image generation time is reduced, then the frame rate could be increased to give user a smoother display.

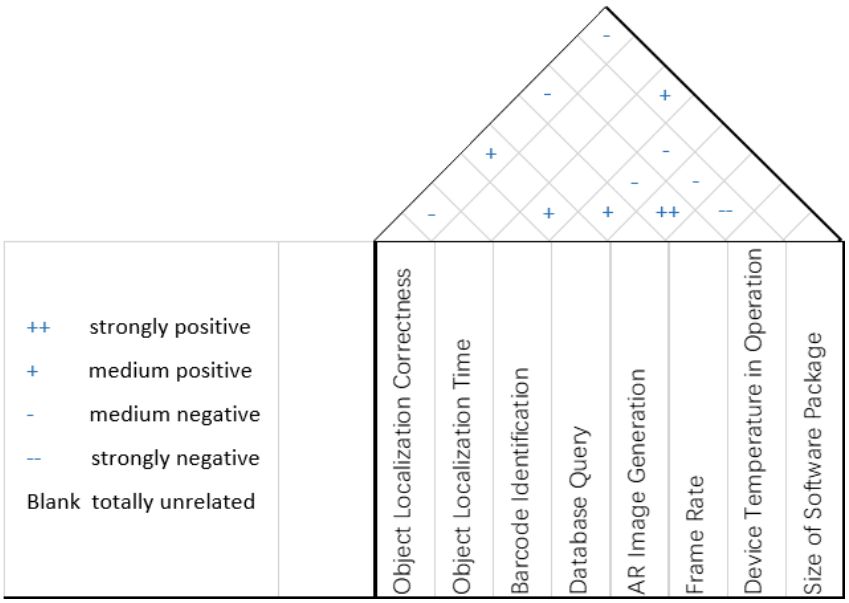


Figure 11: Cross Correlation of ES

4.2.4 Correlate CR to ES

The correlations between CR and ES are shown in Figure 12. Correlation values include ”9”, ”3” and ”1”, where ”9” means strongly related, ”3” means somewhat related, ”1” means weakly related and empty means unrelated. The requirement of short reaction time is related to the time of a series of operations in our application as well as the frame rate. Among these operations, object localization and database cost more time than the others, which have a larger effect on short reaction time. As for information correctness, the most important step is to fetch the correct information from database. Comfortable display requires a high frame rate. The time for AR image generation and the temperature of the device can also influence the display. Finally, a small software package size is needed for the portable device requirement.

	Object Localization Correctness	Object Localization Time	Barcode Identification	Database Query	AR Image Generation	Frame Rate	Device Temperature in Operation	Size of Software Package
Short Reaction Time		9	3	9	3	3		1
Information Correctness	3			9	1		1	
Comfortable Display	1				3	9	3	1
Portable Device							3	9

Figure 12: Correlation between CR and ES

4.2.5 Importance Rating

According to the correlations between CR and ES, we calculate the absolute importance as well as the relative importance of our engineering specifications, and then rank them. As shown in Figure 13, the critical-to-quality ES of our product are database query, frame rate and size of software package.

	Object Localization Correctness	Object Localization Time	Barcode Identification	Database Query	AR Image Generation	Frame Rate	Device Temperature in Operation	Size of Software Package
Absolute Importance	4	9	3	18	7	12	7	11
Relative Importance %	5.63	12.7	4.23	25.4	9.86	16.9	9.86	15.5
Rank Order of Ecs	7	4	8	1	5	2	5	3

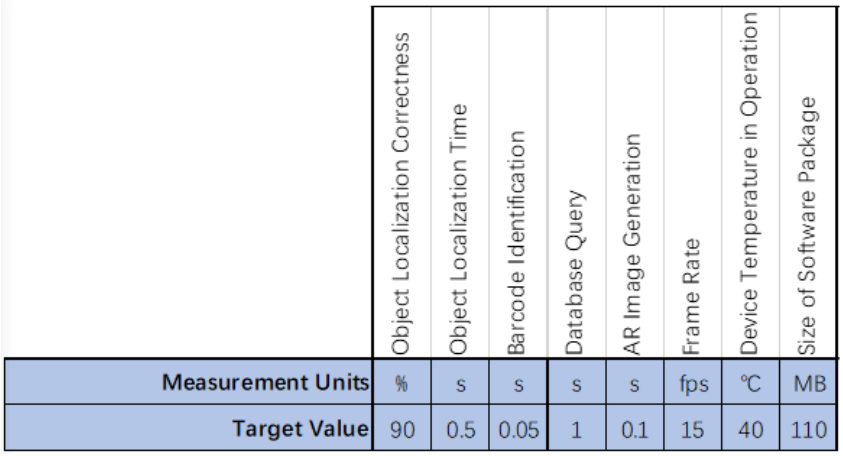
Figure 13: Importance Rating

4.2.6 Benchmark Competitions Against ES

For both Mobile Augmented Assembly and IBM products, the methods they use are different from our ES. In this way, it is hard to do a direct comparison on object location correctness and time, bar code identification and data query. AR image generation, frame rate, device temperature and the size of software packages are not provided in the literature.

4.2.7 Set Targets for ES

Figure 14 shows the target values and the units for ES. The target values are set mainly according to state-of-the-art technologies and the details of setting the target values for ES are presented in Section 4.1.



	Object Localization Correctness	Object Localization Time	Barcode Identification	Database Query	AR Image Generation	Frame Rate	Device Temperature in Operation	Size of Software Package
Measurement Units	%	s	s	s	s	fps	℃	MB
Target Value	90	0.5	0.05	1	0.1	15	40	110

Figure 14: Targets for ES

4.3 Summary of Engineering Specifications

Engineering Specifications	**Measurement Units**	**Target Value**
Object Localization Correctness	%	90
Data Retrieval Accuracy	%	99
Object Localization Time	s	0.5
Barcode Identification Time	s	0.05
Database Query Time	s	1
AR Image Generation Time	s	0.1
Frame Rate	frames/s	15
Device Temperature in Operation	℃	40
Size of Software Package	MB	110

Table 1: Summary of Engineering Specifications

5 Project Plan

Our gantt chart is shown in Figure 15. Our nearest milestones are before design review 2, we divide our project to 2 tasks. One is the Flowgate part, and the milstone is to achieve an app that if we input the ID of a server, we can get its corresponding information. The other is AR part. The goal is achieve a real-time AR app that can scan the scene and display information. Before design review three, we want to finish the integration of two parts and complete a prototype, which allows the most basic function. These three milestones are most important. After then, we can improve our product by developing better UI, dealing with multiple bar codes simultaneously, and making it multi-platform.

5.1 Milestone 1.1: Fetch Data from Flowgate

As we have introduced in Section 2.3.1, Flowgate is a integrated software system having access to all types of data. It has documents of APIs. The APIs are very similar to standard HTTP and REST conventions in its use of HTTP verbs. To get the information, we can use the API *getAssetByID*. For instance, *GET /v1/assets/07bbf9102358434cb124990e72b97033 HTTP/1.1 Host: localhost:8080* [3]. Our problem is to use the APIs in our codes under different platforms and languages.

5.2 Milestone 1.2: Creating AR App

In this step, our original expectation is to use Android. However, since we were not familiar with Android development, we met quite a lot configuration bugs when building the project. Thus, we decided that one of the members who had used Swift to develop applications before would first complete this step by Swift.

In this step, we need to first check how to implement an AR application in iOS. The main focus is on ARkit and Scenekit. The student needs to get familiar with the functions provided. After a basic understanding, the student should be able to build an AR app on iPhone. In this AR app, certain information can be displayed on a required position with an acceptable user interface.

We also hope another student can work on scanning bar code. There are existing packages for both Android and Swift to scan bar code. The student needs to get to know how the package works so that she can not only get the information inside the bar code, but also get the position of the bar code. The student also needs to consider how to coordinate the position with the AR 3D postion.

After these two basic functions' complement, we want to integrate them together so that we can complete an app so that we can scan the bar code and display the bar code infomation on the bar code position.

5.3 Milestone 2: Implementing Prototype

We plan to finish the above two milestones before Oct. 26th. Then we want to start integrate the above two parts: the data fetch part and AR scan part. VMware company suggested us planning to spend about one-third of time working on the whole project to do the integration, since integration can always have unexpected situations. Thus, we arranged integration from Oct. 26th to Nov. 16th with about 3 weeks. During this time, we want to complete a prototype application installed on our phone. Opening the app, we can scan the bar codes, get information (server ID) from the bar code, fetch detailed data from Flowgate and display the useful information on the corresponding place in the phone.

The potential risk of the milestone might be the VPN. We are renting the sever from our college to install the Flowgate environment. However, we can only get access to the server from the internal networking. We need to wait our school IT to change the internal networking to public networking.

5.4 Milestone 3: App with Good User Interface

After having a basic knowledge of how AR works and presents on a phone/pad, we can have more detailed UI designs. In this step, we will decide how to show the information and how to interact with the app. We can try many user interfaces and show different types of information. During the implementation of prototype and after the implementation of prototype, we can continue on improving our user interface.

5.5 Milestone 4: Multiple Bar Codes Situation

After implementing the most basic prototype, we need also consider some more complicated situations. For instance, how should the application perform if there are multiple bar codes inside the scence? This will relate to more complicated algorithm and structure. Also, it may cause more bugs.

5.6 Milestone 5: Multi platform

If time permits, we want to implement this application both on iOS devices and Android devices. We will first work on the iOS version. After Nov. 16th, we will not need every one to work on the iOS version and we will be familiar with implementing process. Then, hopefully, we may implement it on Android.

5.7 Final Implementation

Before the final report and final presentation, we will do many tests and try to make the product stable. The tests will include many boundary conditions which are specified in Section 4.2. Also, during the whole project, one student will keep maintaining the Flowgate database and server.

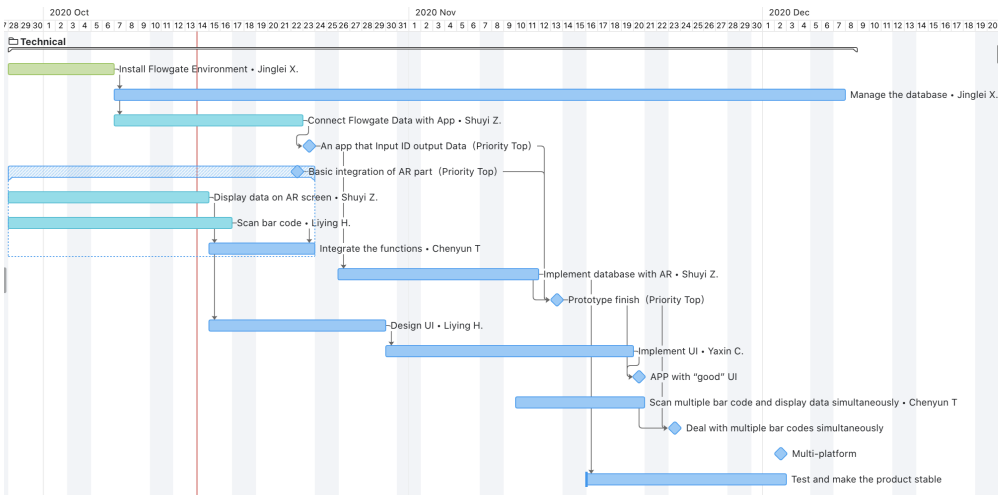


Figure 15: Gantt chart of project.Starting from Sep.28th. End with Dec.7th.

6 Q&A

In the oral presentation of Design Review 1, the Judge Panel raised two questions about our project, and the questions and answers are stated in this section.

1. Why do you assign the reference number 2 to "Mobile Augmented Reality in Data Center (IBM)", while the exact number of the citation listed below is 1?
   Answer: It is a mistake, and we will pay attention to this problem.

2. What does the customer requirement "comfortable display" refer to?
   Answer: It means ensuring a smooth display and an appropriate temperature of the device for the customers.

7 Conclusion

Our project, AR in Data Center, is about applying augmented reality in data centers. In this report, we provide necessary background and introduction to the project, literature review on existing related products, customer requirements, engineering specifications and project plan. To sum up, our project should produce an app that could obtain all kinds of information related to a specific data center from the back end database Flowgate, and display necessary information using AR to facilitate data center maintenance and audit work. The customer requirements include short reaction time, information correctness, comfortable display, and portable device. By conducting literature search and considering the constraints in reality, we further set up the engineering specifications based on the requirements. To help us complete the project, we divide it into several tasks and set milestones. The next milestones are to achieve an app that is able to output the corresponding information based on server's ID, as well as to process the AR part.

References

[1] M. F. Abadi, F. Haghighat, and F. Nasiri, "Data center maintenance: applications and future research directions," Facilities, vol. 38, no. 9/10, pp. 691–714, 2020.

[2] M. Ayat, M. Sharifi, S. Ibrahim, and S. Sahibudin, "CMDB Implementation Approaches and Considerations in SME/SITU's Companies," 2009 Third Asia International Conference on Modelling & Simulation, 2009.

[3] Vmware. "Flowgate." GitHub. [Online]. Available: https://github.com/vmware/flowgate. Accessed: Sept. 27, 2020.

[4] A. B. Craig, Ed., "Understanding Augmented Reality", San Francisco, Morgan Kaufmann, 2013.

[5] M. Hakkarainen, C. Woodward and M. Billinghurst, "Augmented assembly using a mobile phone," 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, Cambridge, 2008, pp. 167-168, doi: 10.1109/ISMAR.2008.4637349.

[6] S. Deffeyes, "Mobile augmented reality in the data center," in IBM Journal of Research and Development, vol. 55, no. 5, pp. 51-55, Sept.-Oct. 2011, doi: 10.1147/JRD.2011.2163278.

[7] N. Fiona, "A Study on Tolerable Waiting Time: How Long Are Web Users Willing to Wait?", Behaviour & Information Technology - Behaviour & IT, 2003, pp. 285, doi: 10.1080/01449290410001669914.

[8] Q. Peng and Y. Song, "Object recognition and localization based on Mask R-CNN," Journal of Tsinghua University (Science and Technology), 2019, vol. 59, no. 2, pp. 135-141.

[9] E. Ohbuchi, H. Hanaizumi and L. A. Hock, "Barcode readers using the camera device in mobile phones," 2004 International Conference on Cyberworlds, Tokyo, Japan, 2004, pp. 260-265, doi: 10.1109/CW.2004.23.

[10] A. Baek, K. Lee, and H. Choi, "CPU and GPU parallel processing for mobile Augmented Reality," vol. 1, pp.133-137, 2013, doi: 10.1109/CISP.2013.6743972.

[11] O. Oktay et al., "Stratified Decision Forests for Accurate Anatomical Landmark Localization in Cardiac Images," in IEEE Transactions on Medical Imaging, vol. 36, no. 1, pp. 332-342, Jan. 2017, doi: 10.1109/TMI.2016.2597270.

[12] LabCE, "Data center operations supported by augmented reality," MediaLab. [Online]. Available: https://www.labce.com/spg650115_barcode_reading_and_accuracy.aspx. Accessed: Oct. 10, 2020.

[13] A. Craig. Augmented Reality Hardware, pp. 69-124, 2013. doi: 10.1016/B978-0-240-82408-6.00003-5.

[14] Apple. “Keeping iPhone, iPad, and iPod touch within acceptable operating temperatures.” Apple. [Online]. Available: https://support.apple.com/en-us/HT201678. Accessed: Oct. 10, 2020.

[15] Google. “Safety & regulatory manual (Pixel 3 & Pixel 3 XL 2018).” Google. [Online]. Available: https://support.google.com/pixelphone/answer/9134668?hl=en. Accessed: Oct. 10, 2020.

[16] Apple. “ARKit.” Apple. [Online]. Available: https://developer.apple.com/documentation/arkit. Accessed: Oct. 10, 2020.

[17] Google. “Supported Devices.” Google. [Online]. Available: https://developers.google.com/ar/discover/supported-devices. Accessed: Oct. 10, 2020.

[18] L. Blom, “Impact of light on augmented reality,” Diva Portal. 2018.

[19] Apple. “App Store.” Apple. [Online]. Available: https://www.apple.com/app-store. Accessed: Oct. 10, 2020.

[20] Google. “Google Play.” Google. [Online]. Available: https://play.google.com/store/apps. Accessed: Oct. 10, 2020.

8 Appendix

8.1 Bios

8.1.1 Shuyi Zhou

I am Shuyi Zhou, a senior student major in Electrical and Computer Engineering (ECE) exchanged to Germany last year, and the attached picture of myself is taken in Germany. I have learnt courses like data structures and algorithms, computer organization, and computer networks, and become familiar with programming languages like C/C++ and Python. I am currently working as a teaching assistant for *Introduction to Computer and Programming* course. In the future, I will pursue a master degree in Tokyo.

Figure 16: Shuyi Zhou

8.1.2 Chenyun Tao

I am Chenyun Tao, a senior student major in Electrical and Computer Engineering (ECE) at University of Michigan - Shanghai Jiao Tong University Joint Institute (UM-SJTU JI). I like travelling, and the attached picture of myself is taken during my trip to Japan. I have learnt courses like data structures and algorithms, computer organization, and computer networks, and become familiar with programming languages like C/C++ and Python. In the future, I will pursue a master degree, and I have participated in JI's GDP program with University of Michigan, School of Information.

Figure 17: Chenyun Tao

8.1.3 Liying Han

I am Liying Han, a senior student major in Electrical and Computer Engineering (ECE) at University of Michigan - Shanghai Jiao Tong University Joint Institute (UM-SJTU JI). I have learnt courses like data structures and algorithms, computer organization, and machine learning. I am familiar with C/C++ and Python programming languages. In the future, I want to go abroad and study in the field of machine learning algorithms.

Figure 18: Liying Han

8.1.4 Yaxin Chen

I am Yaxin Chen, a senior student major in Electrical and Computer Engineering (ECE) at University of Michigan - Shanghai Jiao Tong University Joint Institute (UM-SJTU JI). I have learnt courses like data structures and algorithms, computer organization and methods and tools for big data, and currently I work as a teaching assistant for operating systems course. I am familiar with C/C++ and Python programming languages. In the future, I want to study in the field of distributed systems.

Figure 19: Yaxin Chen

8.1.5 Jinglei Xie

I am Jinglei Xie, a senior student major in Electrical and Computer Engineering (ECE) at University of Michigan - Shanghai Jiao Tong University Joint Institute (UM-SJTU JI). I am really interested in the field of computer science and information systems, and have taken various related courses like operating systems, big data, computer network, artificial intelligence, etc. I am familiar with several kinds of programming languages, and has been a teaching assistant for the course *Programming and Elementary Data Structures*. Besides that, I also have robotics related experience, and has attended global competitions as a member of SJTU VEX robotics team. After graduation, I plan to go abroad for further studies, and pursue a master's degree in computer science. Maybe I would like to focus more on systems and networks, since they attract me the most.

Figure 20: Jinglei Xie