Improving User Experiences in Indoor Navigation Using Augmented Reality

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Improving User Experiences in Indoor Navigation Using Augmented Reality

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This **Masters Project Paper** fulfills the Master of Engineering degree requirement.

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Abstract

Indoor positioning systems help in the localization of objects or spaces inside a building, where Global Positioning System (GPS) and cellular network don't work effectively. These systems can be much more useful than just localizing objects, if they are augmented with relevant information on the user interface. This paper demonstrates, with a prototype, one such use case where an indoor positioning system can be made more useful by rendering relevant 3D graphics on the mobile display. It also describes our application development process, right from target user interviews to an interactive high-fidelity prototype development in Android. Localization is achieved by creating a location API simulator and using the orientation sensors in the phone/tablet. Relevant graphical information, determined based on the user's context and selection, is rendered using OpenGL on top of the live camera stream. User studies indicated that overlaying points of interest on the camera view significantly enhanced the user experience in indoor navigation. Localization can be made even more robust with the help of object detection techniques. To summarize, there is a strong untapped potential in augmented reality techniques in the context of indoor navigation and we have attempted to demonstrate this in our application. Our solution is generic and can be easily configured to be used in any indoor space such as malls, hospitals, museums etc.

Acknowledgements

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1. Introduction

Indoor Positioning refers to locating objects or spaces inside a building. Global Positioning System (GPS) does not work accurately indoors due to signal attenuation and reflection caused by roofs and walls [1]. Hence in most situations, GPS based location tracking does not produce useful results. As a result, most of the popular indoor positioning systems work on technologies such as Wi-Fi, Bluetooth, Radio beacons which are more accurate than GPS. Furthermore, accurate location determination of indoor spaces could have numerous interesting applications if integrated with augmented reality. Indoor navigation systems have started incorporating augmented reality techniques to visually help the user in navigating indoors.

User experience is critical in indoor navigation systems. This is more relevant in large indoor spaces such as malls, museums, airports etc. where displaying the location on a 2D map would not necessarily give a good user experience. There is a need for some clear visual indicators to create an appealing and a convenient experience for the users of such indoor navigation systems. Maps can only be useful in tracking the location of a person or object whereas with augmented reality, a lot of relevant information can be displayed along with the location information. There is a strong untapped potential in augmented reality techniques, with respect to indoor navigation. Indoor navigation systems can be useful in a variety of interesting applications, apart from localizing an object or a user indoors. For instance - in the British Museum [2], when a visitor orients his phone towards a particular painting, relevant information (such as history of the artist, images of similar paintings etc.) pops up on his screen. This is possible if his relative location in the museum is known.

In this paper, we demonstrate how augmented reality can enhance the utility of indoor positioning systems. The *Literature Review* section gives an overview of the various technologies used in indoor positioning systems and the existing landscape (key players) in this market. It is followed by the *Methodology* section, which describes how we targeted a specific user scenario and the technologies we used to develop an augmented reality based prototype. We then discuss the user study results in the *Results* section. Finally, the *Conclusion* section summarizes the paper and briefly discusses possible future work in this area.

2. Literature Review

2.1. Technology

This section gives an overview of some of the most popular technologies used in Indoor Positioning Systems - Global Positioning System (GPS), Wi-Fi, Bluetooth and Infrared.

GPS

The satellite based GPS is more suitable for positioning outdoors. As mentioned above, it does not work well in a relatively closed environment due to signal attenuation. Reflections across different indoor surfaces further reduce the signal accuracy [1].

Bluetooth

Bluetooth is a wireless technology standard used for exchanging data over short distances. It uses radio waves in the range of 2.4 to 2.483 GHz [3]. The positioning algorithm is based on estimating the power of radio wave signals received by the device [4]. Using Bluetooth is highly secure, cost effective and low in power consumption [4]. However it has certain drawbacks. It works over short distances only, hence a large number of receivers are required to cover a wide area. It runs the device discovery procedure for each localization attempt, thereby increasing the latency by 10-30 seconds [4]. Localization systems based on Bluetooth are explained in detail in [5] and [6].

Infrared

Infrared systems are highly accurate short-ranged positioning solutions. In one of the commonly used positioning techniques, a device is localized with the help of a unique IR signal emitted every ten seconds by its badge. IR sensors placed at different locations capture these signals and communicate with a central location management server. However, these systems have high installation and maintenance costs. [7]

Wi-Fi

Wi-Fi is the most commonly used technology for indoor positioning. Wi-Fi access points are usually installed in most indoor spaces. Each access point works over a medium range (25-50 meters) [8] which is ideal for indoor positioning. The device's location is estimated using vectorization by tracking it relative to the location of access points on the floor.

Table 1 [4] shows a comparative analysis based on accuracy, coverage, power consumption and cost.

System	Accuracy	Coverage	Power consumption	Cost
GPS	6 - 10 m	Good outdoor, poor indoor	High	High
Bluetooth	2 – 5 m	Indoor	Low	High
Infrared	1 – 2 m	Indoor	Low	Medium
Wi-Fi	1 - 5 m	Building level (indoor)	High	Low

Table 1: Comparison of commonly used technologies for localization [4]

2.2. Industry Landscape

An extensive landscape study of the indoor navigation domain sheds light on the existing products that dominate the market. We studied and compared some of the prominent indoor navigation systems such as Qualcomm's IZAT, Google Indoor Maps, Place Lab Intel Research, NAVVIS and InfSoft.

Qualcomm Indoor Location Technology

Qualcomm's indoor location technology (IZat) is a chip-based platform that facilitates delivery of location-aware networks. Qualcomm Atheros' 802.11ac and 802.11n access point solutions include advanced Wi-Fi based calculations to localize devices indoors with an accuracy of 5 meters. These access points, in conjunction with a server component they interact with, form a cohesive indoor positioning system. [9]

Figure 1 shows the different components in Qualcomm's IZat system.

Figure 1: Qualcomm's IZat [9]

Google Indoor Maps

Google Indoor Maps have been activated for over 10,000 floor plans throughout the world [10]. These indoor spaces include airports, malls, museums etc. Its indoor navigation algorithm is based on Wi-Fi access points and mobile towers to determine user's location [11]. Figure 2 shows a snapshot of Google's indoor navigation solution.

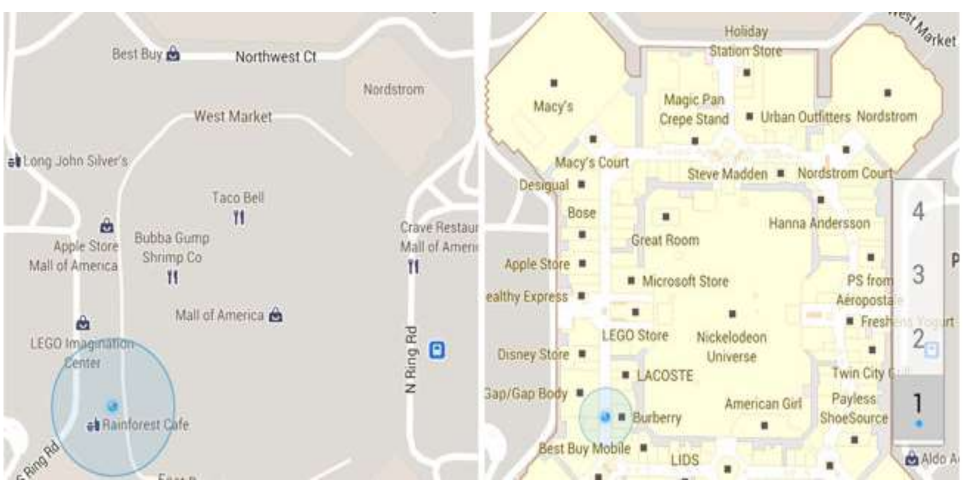


Figure 2: Google's Indoor Navigation [10]

Place Lab – Intel Research

The Place Lab architecture, developed for research purposes, consists of three key elements as shown in Figure 4: Radio beacons installed at various places indoors, Databases containing the beacon location information and clients that estimate their location from this data. Place Lab provides location based on known positions of the access points which are provided by a database cached on the detecting device. Place Lab is entirely dependent on the availability of beacon locations, without which it cannot estimate anything about the current location. [12] Figure 3 shows Place Lab's user interface, while Figure 4 gives an overview of its architecture.

Figure 3: Place Lab UI [13]

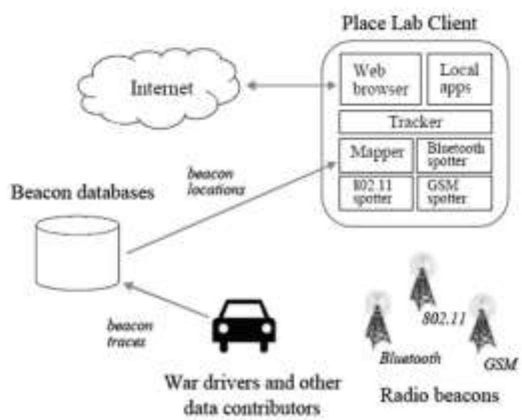


Figure 4: Place Lab architecture [12]

NAVVIS

The NAVVIS positioning system works on a large database of images of indoor places and generates a 3D model of that place. The user needs to take a picture of his surroundings and NAVVIS compares it with the images in the database to compute the user's current location and orientation. It is also smart enough to analyze the picture provided by the user for any changes in the indoor space and update its database accordingly. [14] Figure 5 shows NAVVIS's user interface in action.

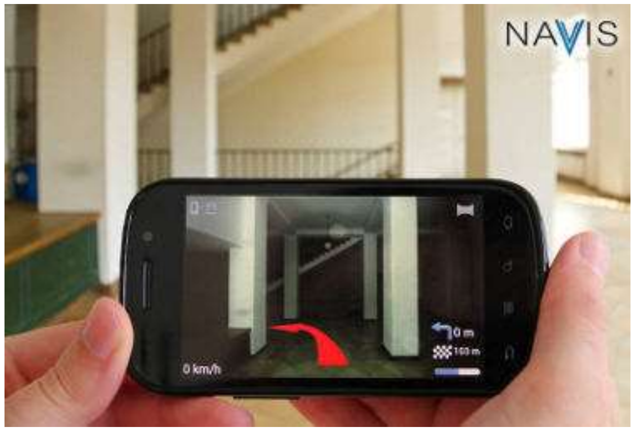


Figure 5: NAVVIS UI [14]

InfSoft

InfSoft makes use of multiple wireless technologies – Wi-Fi, Bluetooth and GPS to localize an object indoors. It further implements augmented reality to overlay the device's camera view with relevant navigational information as shown in Figure 6. [15]

Figure 6: InfSoft UI [15]

2.3. What sets us apart?

Similar to NAVVIS and InfSoft, our system leverages augmented reality to render relevant information on the user interface. However unlike any of the existing systems, our solution overlays points of interest on the live camera stream ***based on user's context*** – while NAVVIS and InfSoft just have arrows rendered on screen to help user navigation, our application has a wide range of functionalities based on the user's preferences (described in the following sections). It provides a rich user experience by enhancing interactivity with virtual objects on screen. Another differentiator is that our solution provides a generic framework that can be easily tailored and applied to almost any indoor space.

3. Methodology

We decided to develop an Android application (Augmented Lab) to demonstrate the usefulness of combining augmented reality with indoor positioning. We needed access to an existing indoor positioning API to accurately determine the smartphone's location and a 2D map of the indoor space. As such, our application could accommodate any indoor positioning API. Our industrial sponsor was Qualcomm Research Silicon Valley and we started working on this project hoping to use their indoor positioning platform (IZat). However, due to licensing hurdles, we could not get access to IZat and we had to simulate an indoor positioning API to serve our purpose.

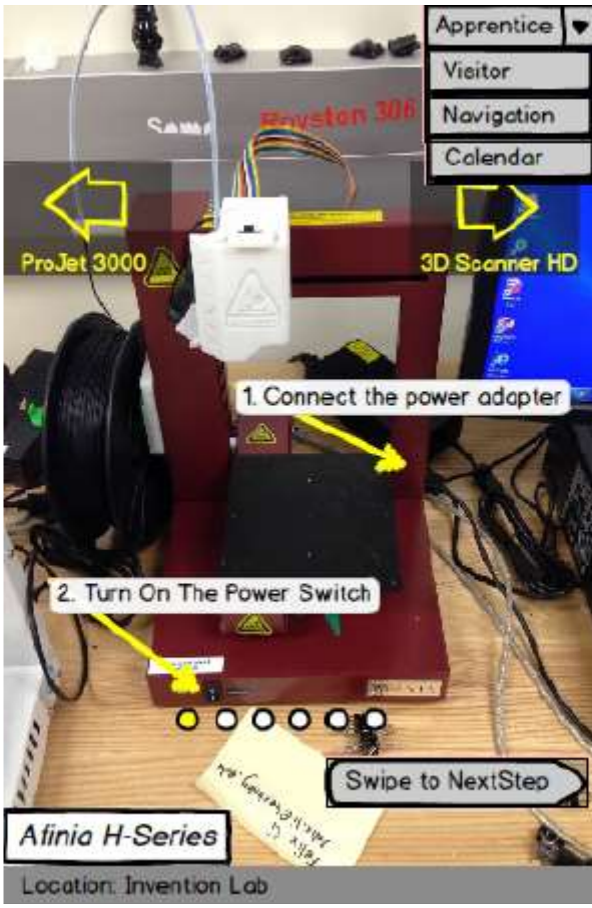
The application development process was sub-divided into the following chronological stages:

3.1. Targeting a specific user scenario

We targeted a specific user scenario for this project. We got access to the CITRIS Invention lab in the University of California Berkeley, where students work on 3D printers, laser cutting tools and other such devices. To recognize frequently used devices in the lab and important use-cases that are relevant to the users, we conducted some initial user interviews with the lab managers, students and lab visitors. From these interviews, we identified two types of potential users – students or faculty who use these devices and visitors who take a lab tour to check out different devices and their demo products. Consequently, we determined four broad use-cases – learning how to use the devices in the lab (apprentice mode), taking a tour to see cool demo products (visitor mode), navigating to different devices in the room (navigation mode) and checking which devices are currently being used (calendar mode).

3.2. Developing a mockup user interface

Based on the feedback from our interviewees, we designed a low fidelity prototype using Balsamiq – a user interface generator that helps build simple interfaces without writing any code to back them up. User tasks were simple – selecting one of the four modes based on his or her preference and pointing the phone/tablet towards a particular device in the lab. The application detects each device's location relative to that of the user and the user interface primarily shows relevant graphics and text overlaid on top of the camera view. The overlaid content depends on the selected mode. In case of the apprentice mode, the user can go through an interactive step-by-step guide explaining how to use that particular device. Figure 7 shows the apprentice mode in a mockup Balsamiq UI assuming that the phone is being pointed towards a 3D printer. If the user switches to the 'Visitor' mode, an interactive gallery of pictures and 3D models of finished products (created/designed using the lab devices) would be rendered on screen as shown in Figure 8.



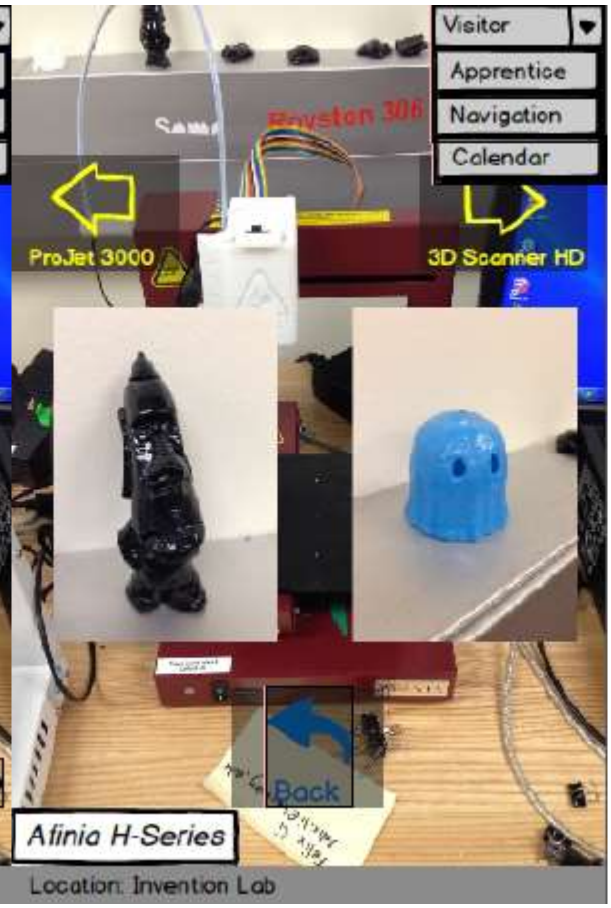


Figure 7: Balsamiq UI - Apprentice Mode

Figure 8: Balsamiq UI – Visitor Mode

If switched to 'Navigation' mode, 3D arrows and text labeling all devices in view would be overlaid on the camera view as shown in Figure 9. Finally, in the 'Calendar' mode, the application graphically (using 3D arrows) shows which devices are currently being used or scheduled to be used soon – the user can apply these filters using checkboxes as shown in Figure 10.

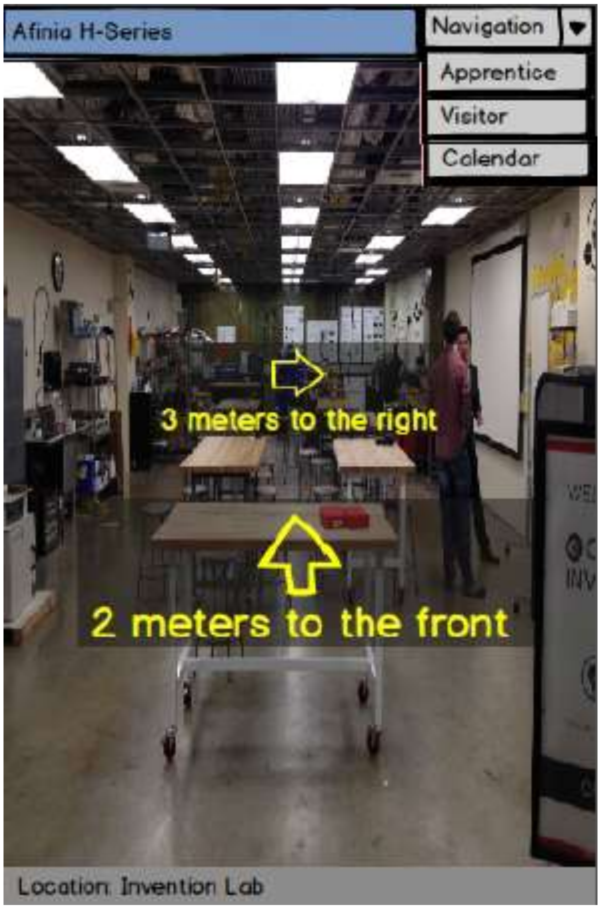


Figure 9: Balsamiq UI – Navigation Mode

Figure 10: Balsamiq UI – Calendar Mode

We did a round of user testing with the mockup UI to validate our understanding of the use cases. Our testers were the managers and device users in the lab. From the functionality perspective, the test users seemed excited about the application. We received feedback related to certain UI elements. Once our basic ideas were validated, we started implementing the actual prototype on the Android platform.

3.3. Developing an interactive prototype

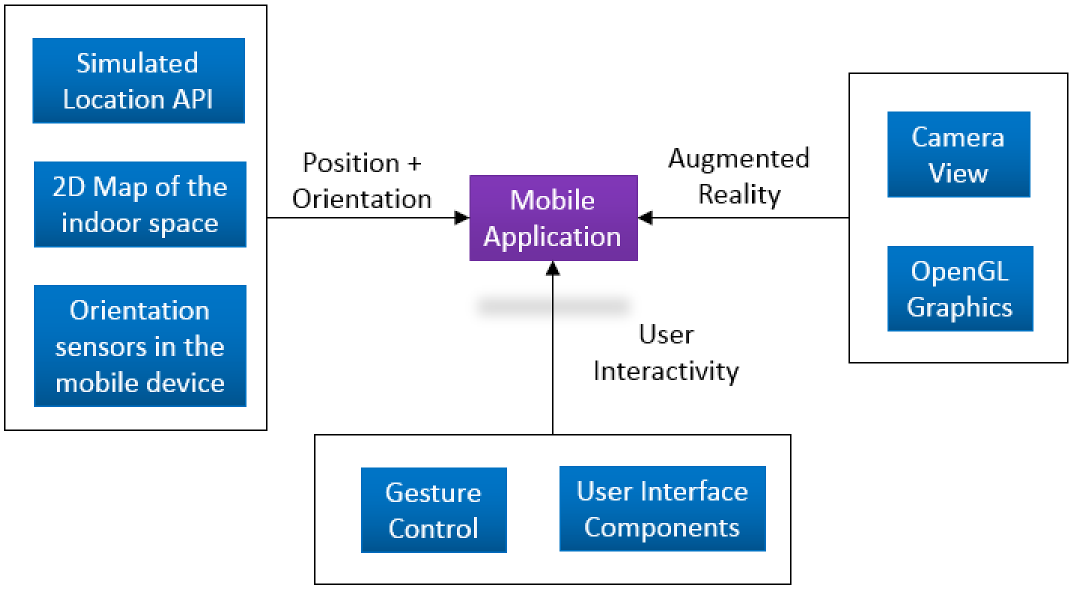


Figure 11: Modules in our application

Figure 11 shows that the modules in our application are broadly categorized into three sections – the "Position + Orientation" section roughly determines the phone's location and orientation, the "Augmented reality" section renders relevant graphics on top of the camera view and the "User Interactivity" section gels everything together and provides a rich interactive experience with the help of gesture control. Rest of this section discusses each module in detail (link to our source code: https://github.com/axzhong3/ARVisionMap)

As mentioned before, we could not get access to Qualcomm's proprietary indoor location API. So we created a simulated location API to work-around this issue. As shown in Figure 12, we designed a website (http://augmentedrealitymap.appspot.com/) that highlights a particular location on Google Maps. The initial location is that of a point in the CITRIS Invention lab in the

University of California, Berkeley and we can manually move it in all four directions. Different devices in the lab are marked on this map. The website maintains the current coordinates in the JSON (JavaScript Object Notation), a popular data interchange format. Meanwhile, our application continuously (after every 10 seconds) fetches the coordinates (latitude and longitude) from this website using an HTTP Client in Android. We create a JSON Object that parses the coordinate values from our website. A separate thread handles this location fetching mechanism so that the main UI thread can handle the other functionalities in the application.

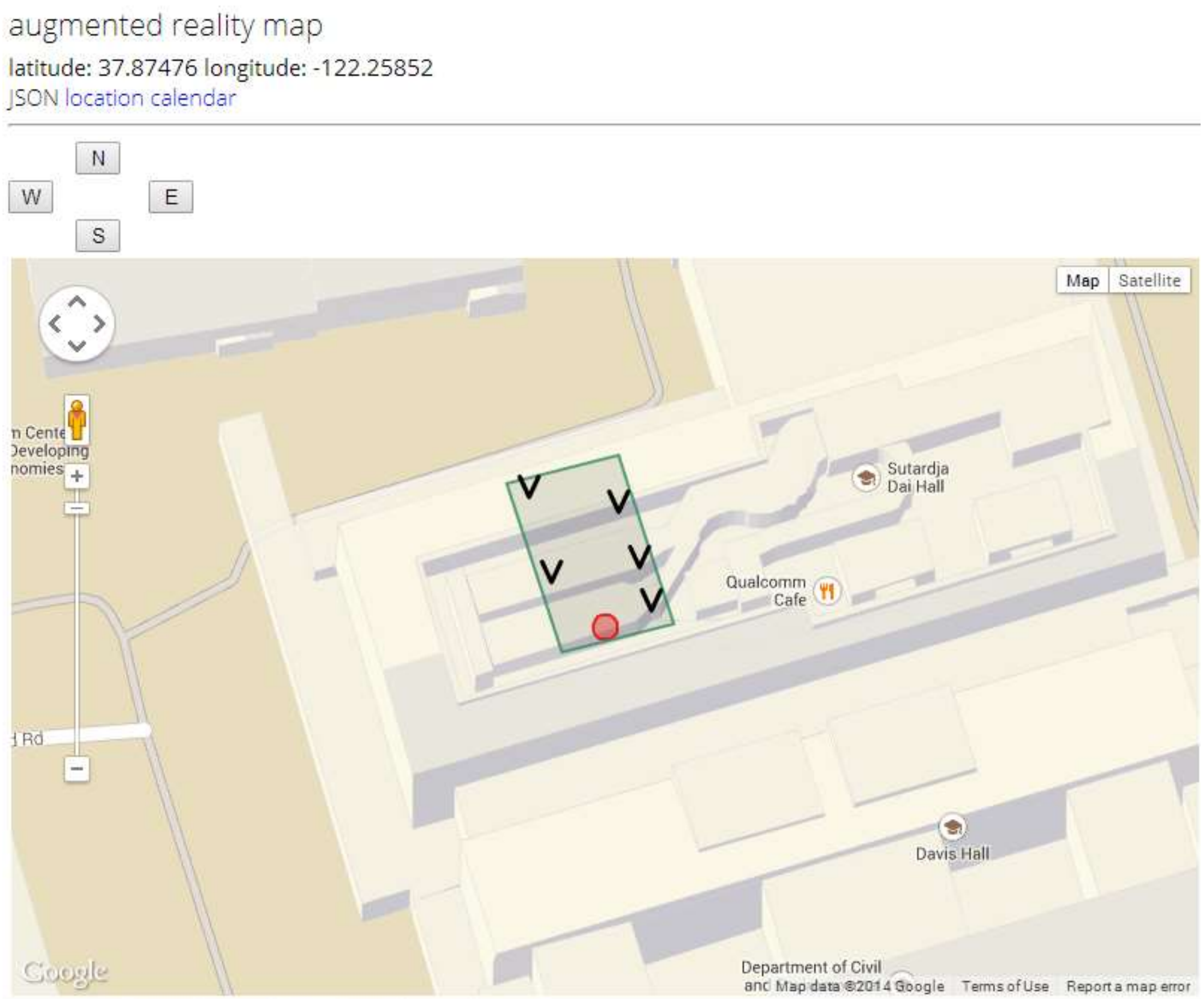


Figure 12: Our website for the simulated Location API

Once the phone's location in an indoor space is determined using the simulated API, we compute its orientation relative to the magnetic north using its accelerometer and magnetometer (orientation sensors). Android provides an easy API to read sensor events and obtain the azimuth, roll and pitch values. Using the location API and orientation values, we can determine which device in the lab lies in front of the user's phone/tablet.

Like any augmented reality system, the base view in our application is the camera view and graphics/text are overlaid on top of it. Initially, we used Android's camera API to interact with the camera hardware of the phone/tablet and access the live image stream. However, we switched over to the camera API provided by OpenCV (Open Source Computer Vision Library), a cross-platform library that deals with real-time image processing. We envisage using object detection techniques in future to make localization even more robust, hence we decided to work with OpenCV's camera API. The image returned by this API forms the lowest layer in our application.

We used OpenGL ES 2.0 to render graphics in Android. OpenGL is a graphics library to render graphic 3D shapes and textures. Figure 13 [16] gives an overview of the OpenGL rendering pipeline. We implemented each of the following rendering stages for all objects to be shown on screen.

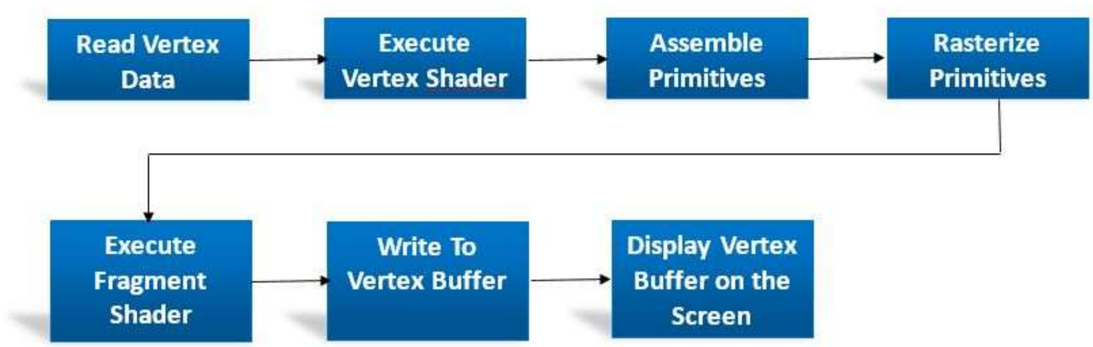


Figure 13: OpenGL rendering pipeline [16]

Shaders are essentially programs which define what to render and how to render. Vertex shaders define the transformations for all vertices in any 2D/3D shape. They are also used to map custom textures on 3D objects. Fragment shaders are used to define the color value of each pixel. We have implemented custom vertex and fragment shaders to render 3D shapes. These shaders are generic, so we reused them for drawing multiple objects dynamically on the screen depending on their projection and view matrices. The projection and view matrices for different objects to be rendered are determined based on the location information provided by the location API and orientation sensor readings. Once the position, color and other attributes of all graphical shapes are determined, they are drawn on top of the live camera stream.

One challenge that we faced here was flexibly writing text on top of the OpenGL layer. OpenGL does not really have an easy method to render text on screen. We solved this problem by using Android's FrameLayout and stacking TextViews on top of the OpenGL layer which is in turn stacked over the camera view.

As mentioned before, the content that goes over the camera view depends on the mode selected by the user. When the application is launched, the default mode is the 'World' mode which displays textures of captions for different devices in the lab – locations of these devices in the object space is directly mapped with their corresponding locations on our map in Figure 12. The application showcases a drop-down menu that contains 'World' mode, 'Navigation' mode and 'Calendar' mode as shown in Figure 14.

Figure 14: Interactive Prototype – Basic mode selection

To enhance user interactivity, we implemented a mechanism that allows the user to select a device by a long press on the corresponding caption. The long press is handled using Android's Gesture API and the selected device is determined by approximating the camera's field of view angle and the phone's current orientation. In the 'World' mode, a long press on a caption results in a dialog box that asks the user to select either 'Visitor' mode or the 'Apprentice' mode as shown in Figure 15.

Figure 15: Interactive Prototype – Device selection in 'World' mode

The ‘Visitor’ mode for a particular device is a gallery of 3D graphical models of products that were designed or created using that device. This mode basically gives an idea to the user of what exactly s/he can do with that device. The graphical models are rendered using OpenGL shaders as described above. The user can rotate each model to view it from different angles as well as pinch-zoom it. This user interactivity has been implemented using Android’s Gesture and Touch APIs. Figure 16 shows a T-Rex model created using the Afinia 3D printer.

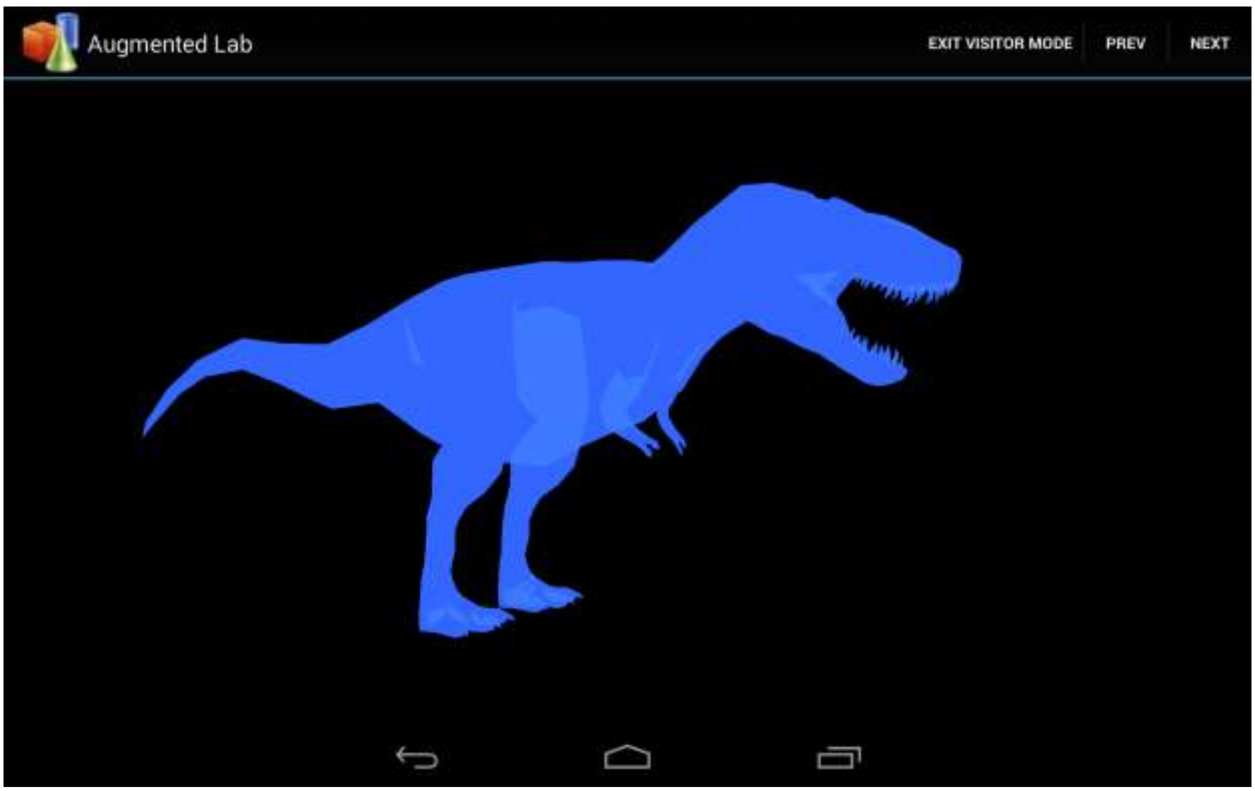


Figure 16: Interactive Prototype – Visitor mode

The ‘Apprentice’ mode has been implemented using Android’s ViewPager. ViewPager is basically a group of “swipe-able” pages. In this mode, each instruction in the “How-to-use” guide is displayed on a ViewPager page. Figure 17 shows one of the instructions for the laser cutting tool.

Figure 17: Interactive Prototype – Apprentice Mode

The user can select the ‘Navigation’ mode from the main drop-down menu (Figure 14) to get graphical navigational information on the screen. The required device can be selected using another drop-down menu that appears specifically for this mode as shown in Figure 18.

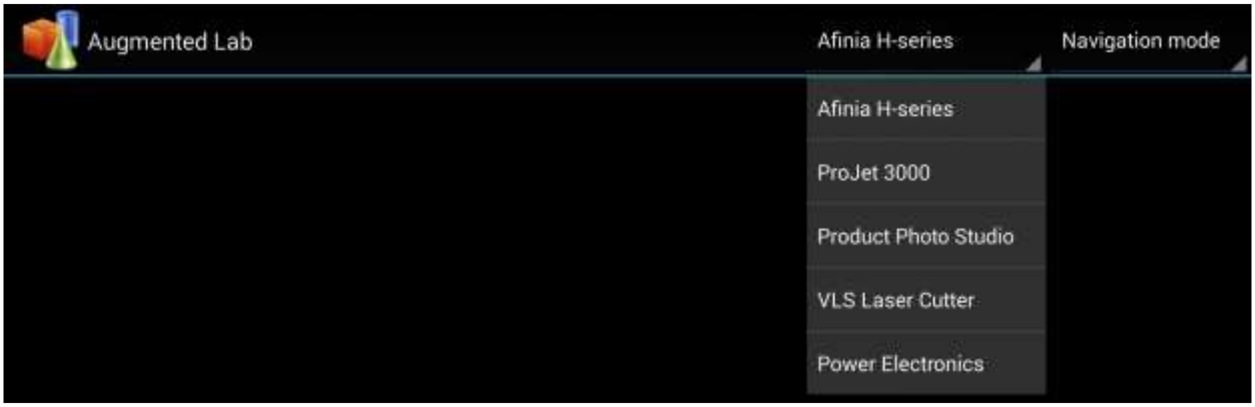


Figure 18: Interactive Prototype – Device Selection in the Navigation mode

Once the user selects the device that s/he is looking for, a flat graphical arrow that points towards the selected device is rendered on the screen. This arrow is rendered using OpenGL vertex and fragment shaders. Figure 19 shows 'Navigation' mode for the Afinia 3D printer.

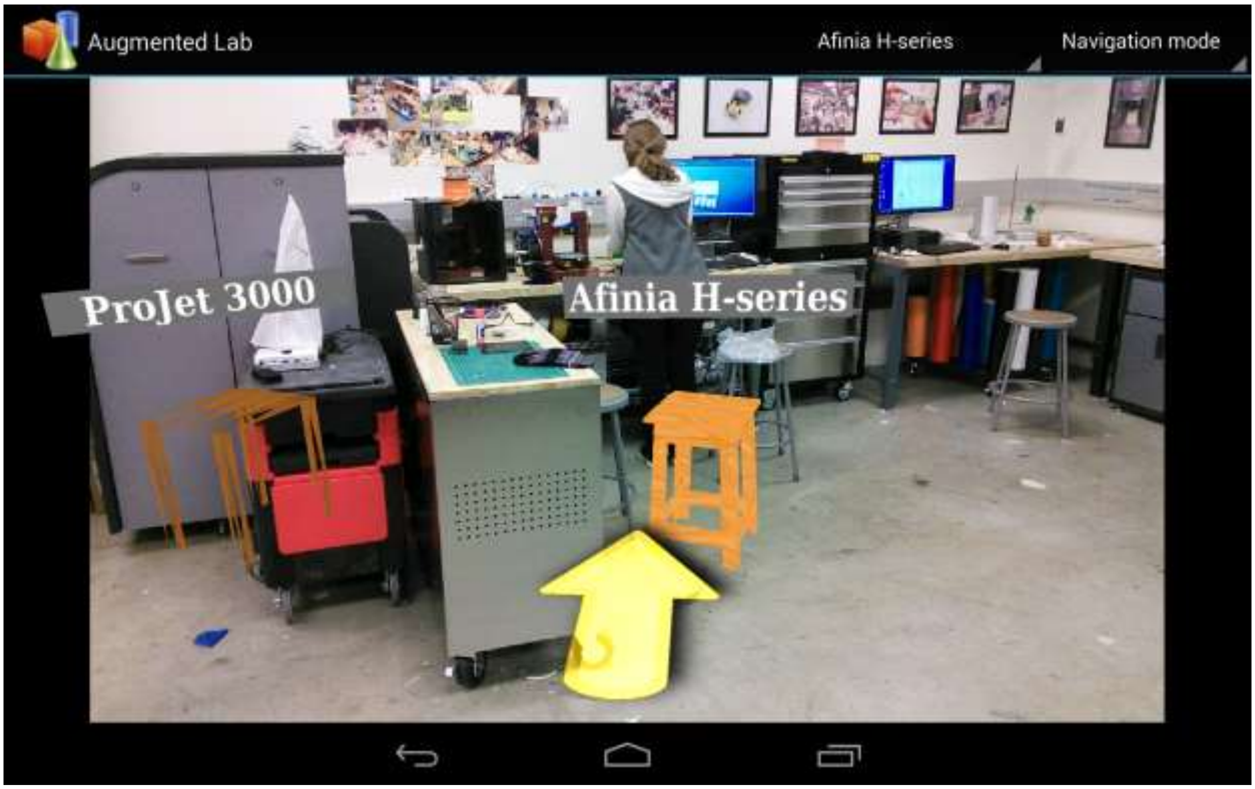


Figure 19: Interactive Prototype – Navigation Mode

Finally, the user can select the 'Calendar' mode from the main drop-down menu to check the current availability or the Google calendar of a particular device. As you can see in Figure 20, the user can select one or more of the three checkboxes to see which devices are currently available, occupied or scheduled to be used soon. The devices are marked with 3D arrows (again rendered using OpenGL shaders) of different colors depending on their status. The user can also do a 'long press' on the caption of a device to see its Google calendar and book a slot accordingly. This has been implemented using Android's WebView that facilitates opening URLs in the application itself, as shown in Figure 21.

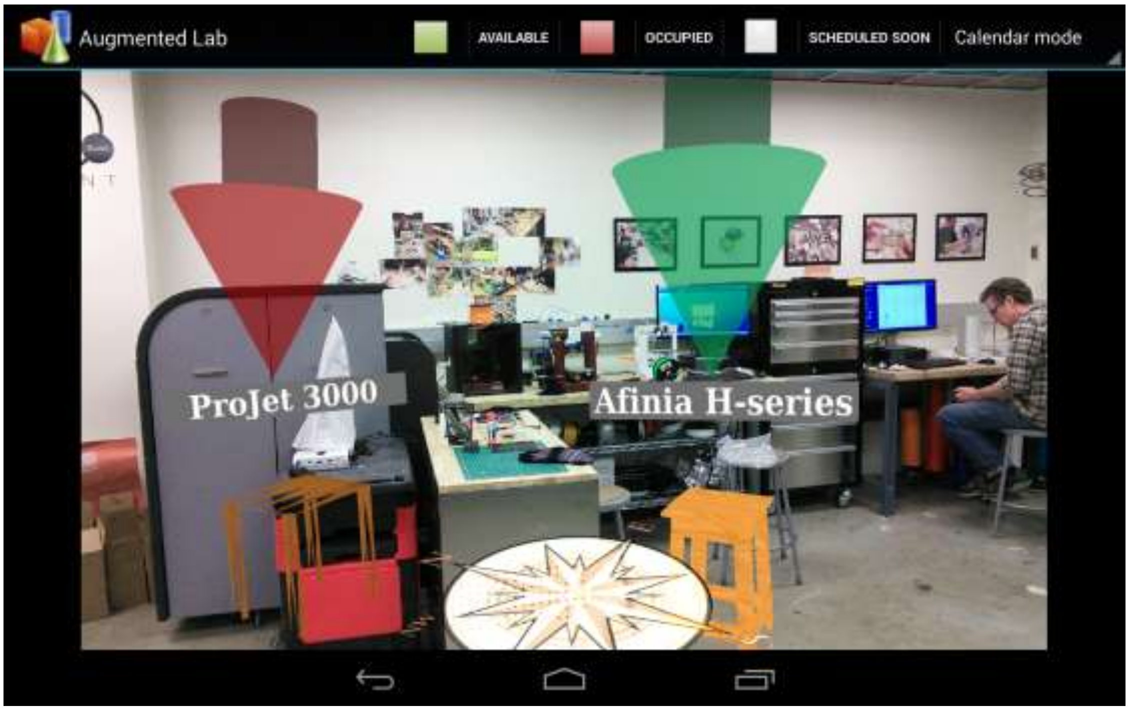


Figure 20: Interactive Prototype – Calendar mode

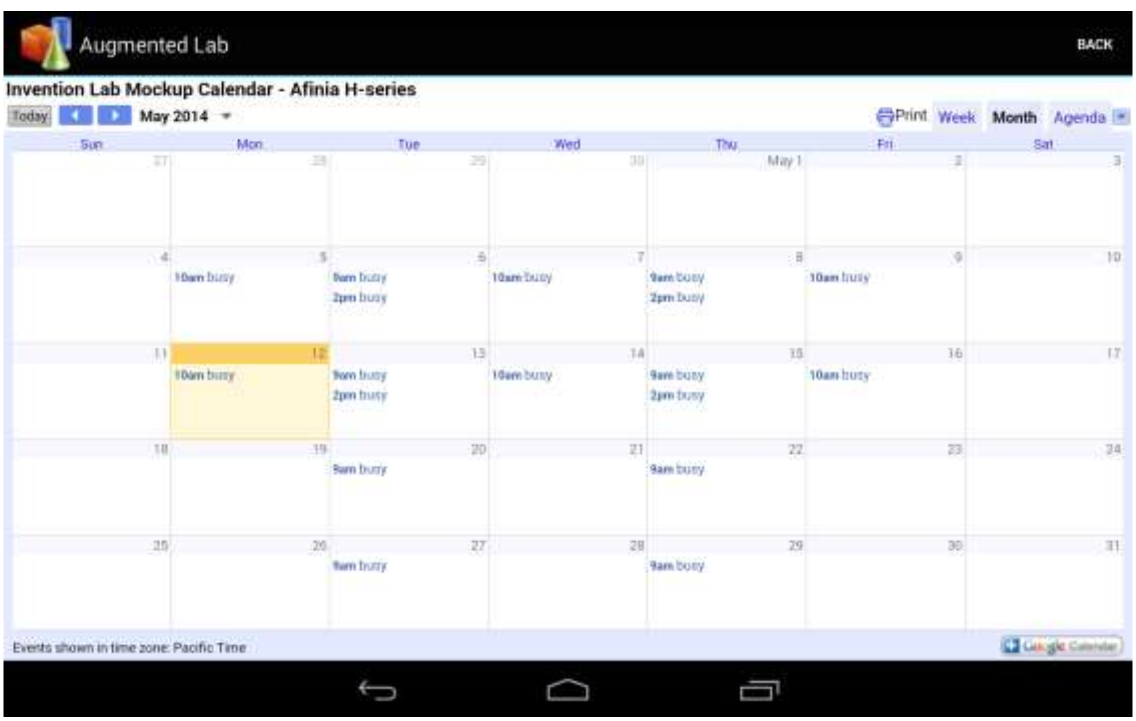


Figure 21: Interactive Prototype – Google calendar of Afinia

4. Results: User Study

We conducted another user study, this time for our interactive prototype. Ten users in the CITRIS Invention lab, UC Berkeley were randomly selected. The study was conducted on the Afinia 3D printer in the lab. The sample set consisted of lab administrators, undergraduate and graduate students who had some experience of working on Afinia. They were asked to try out the different functionalities in our application and then answer some questions related to usability. Some of the highlights are as follows:

Test users were asked to rank different functionalities based on their practicality and usefulness. The 'Apprentice' and 'Calendar' modes turned out to be the most popular features. Figure 22 shows an average ranking for each feature (1 being the highest rank).

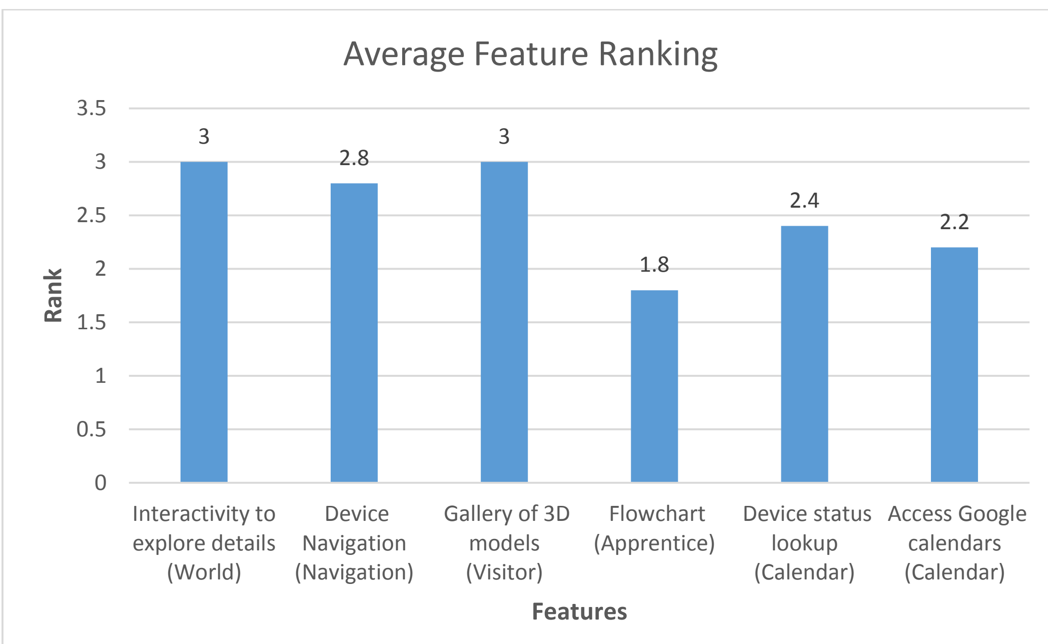


Figure 22: User Study: Average Feature Ranks

The users were also asked if they would prefer using our application instead of the traditional instructions in the form of documents. As we can see from Figure 23, 80% of the users preferred using our application. The remaining 20% preferred documented instructions since they did not find our 'Apprentice' mode detailed enough. They suggested adding links to videos explaining how to use the tools.

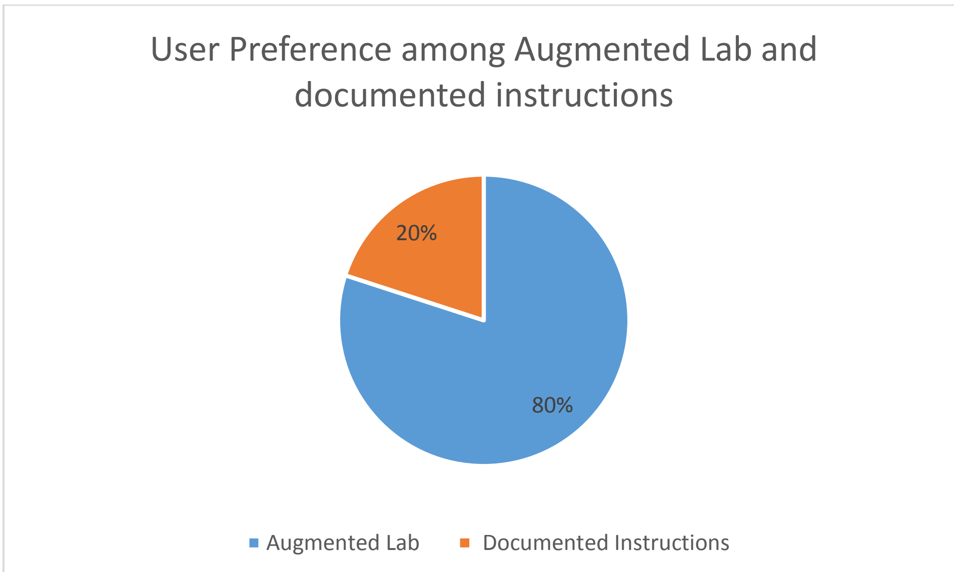


Figure 23: User Study: Comparison of Augmented Lab with Documented instructions

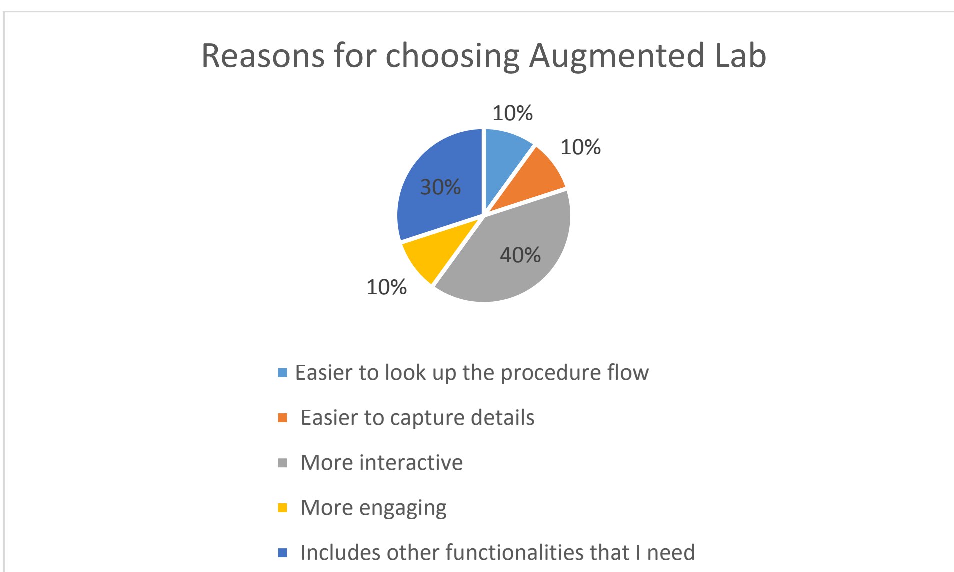


Figure 24: User Study: Reasons for choosing Augmented Lab

The users were also asked for improvement suggestions or general feedback with respect to functionality and usability of the application. Some of them observed that the device captions on the camera view were kind of shaky and should be stabilized. A couple of users suggested that we should also focus on smaller tools (like a screw driver) in the 'Navigation' mode since they are harder to locate as compared to larger ones (like the 3D printer). Some users also recommended maintaining a checklist in the 'Apprentice' mode so that experienced users need not have to go through the entire flowchart.

Overall, the users were quite excited by the visual appeal and varied functionalities in our application and thought that it provided a rich interactive user experience.

5. Conclusion

Future work could include replacing our simulated location API with Qualcomm's indoor positioning system (IZat). We could also implement computer vision techniques to detect objects that are visible in the camera view. At this point, localization in our approach is entirely based on the location API and orientation sensor readings. Integrating object detection in the current approach would make the localization extremely robust, giving an inch-level accuracy. As of now, once the device is detected (based on location and orientation) the 'Apprentice' mode shows static images that explains how to use that device. If we are able to implement a highly accurate object detection algorithm, then we can get rid of the static images in 'Apprentice' mode and render text and 3D arrows accurately pointing to different parts of the device.

We have identified two approaches for object detection in this context. In the first approach, we could add markers on different devices in the lab and detect them in the images taken by the camera. A marker is basically an indicator, with a distinct pattern (color and/or shape) that is easy to detect in an image. An advantage of this approach is that we do not need to implement complex machine learning algorithms to train images since we only need to search for known distinct markers. However, this approach is not really flexible – in case of a huge indoor space with a large number of objects, it is not feasible to add markers on each object. Also, having a lot of markers beats the purpose since the detection won't be trivial anymore. Another approach would be implementing a full-fledged object detection using OpenCV based Haar training. Haar training is used to train sample images, which is a necessary task for any machine learning based object detection task. The detection accuracy depends on how well the system was trained based on a large set of sample images. This approach is complex and the training is extremely time-consuming. However, it is much more scalable and flexible as compared to using markers.

To summarize, there is a strong untapped potential in augmented reality in the context of indoor navigation and we have attempted to demonstrate this to a certain extent in our application. We explored four representative modes ('Apprentice', 'Navigation', 'Visitor', 'Calendar'), each of which could be extended based on different user scenarios. The strength of our approach is that it is completely generic and can be tuned to work with any indoor space such as malls, hospitals, museums, airports etc.

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