# Augmented Reality Based Technology and Scenarios For Route Planning and Visualization

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**Abstract**

Navigation has always been an object of interest to scientists and business industry representatives. There are plenty of ready-to-use applications that use GPS data, designed to make user's navigation easier. Augmented Reality is currently one of the most popular upcoming technologies most commonly known for its use within games and advertising. By combining navigation with augmented reality, it could be possible to obtain new user friendly applications which will be able to quickly help users in everyday navigation. In this study the applied aspects of information system development for routing and visualization of augmented reality routes have been considered. The relevance of the study has been proved by the results of the survey among first-year students of Khmelnytskyi National University (KhNU) on the necessity of assistance in navigation during the first year of the study. An information system in the form of a mobile application has been developed, which provides assistance in routing in real time and reproducing the saved routes using augmented reality technology.

**Keywords**

Smart campus, Augmented reality (AR), Navigation systems, iOS, Mobile Application

## 1. Introduction

The concept of smart cities became quite widespread over the last decade. It includes facilities for dwellers such as smart bus stops, smart parking, inclusive access to city buildings and smart navigation [1].

Currently relevant is the issue of navigating unfamiliar places at short distances, such as a hospital area with plenty of buildings or university campus with lots of different buildings (dormitories, educational buildings, library etc.), where GPS-navigators do not always give accurate data[21].

Nowadays students care for the digitalization and sustainability of their university campuses, work on green-tech projects and want to see their university modern and technological. The territory of Khmelnytsky National University is large enough and occupies 81602.95 square meters. The institution accepts more than 500 new first-year students and about 30 foreign students annually, the survey among the students has been conducted. 78 Ukrainian and 34 foreign students took part in the survey. The results of the survey are shown in Figure 1.

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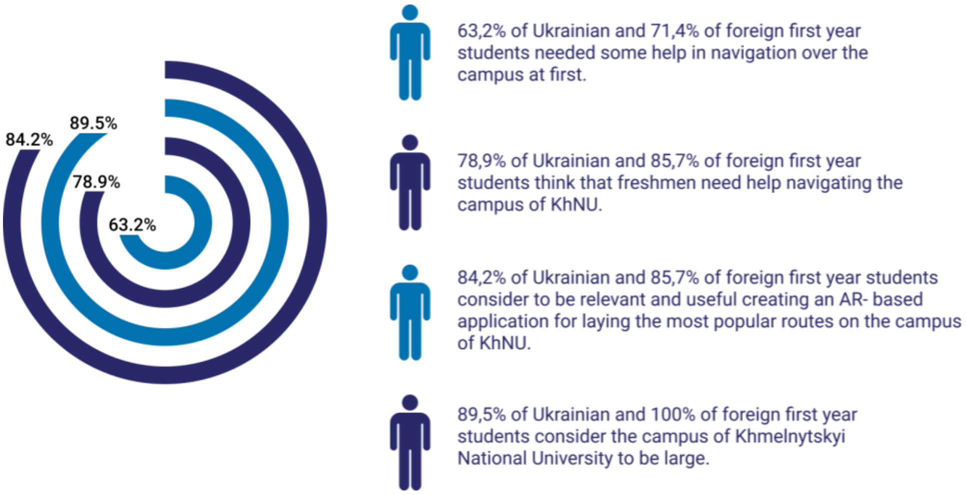


**Figure 1.** Results of the survey among the first-year students of Khmelnytskyi National University

According to the survey, 89,5% of Ukrainian first-year students and 100% of foreign first year students consider the campus of Khmelnytskyi National University to be large.
63,2% of Ukrainian first-year students and 71,4% of foreign first year students responded that they needed some help in navigation (finding the necessary academic buildings, hostel, sport building etc) at first.

78,9% of Ukrainian first-year students and 85,7% of foreign first year students responded that in their opinion freshmen need some help navigating the campus of KhNU.

84,2% of Ukrainian first-year students and 85,7% of foreign first year students consider that it would be relevant and useful to create an augmented reality based application for laying the most popular routes on the campus of KhNU to facilitate the navigation of first-year students and their parents during their first stay on the territory of KhNU.

Considering the relevance of this issue, it was decided to develop the information system for route planning and visualization in the form of mobile application. For the developing augmented reality technologies and GPS data have been chosen.

Therefore, the aim of this work is:

1) conduct the analysis of modern technologies for navigation using augmented reality and GPS data;
2) develop the client-based part in the form of mobile app which provides planning and visualization of routes;
3) conduct the experiment on route planning and visualization in Khmelnytskyi National University campus.

## 2. Domain Analysis

Augmented Reality is an area that is closely related to Virtual Reality in that both utilize a subset of the same tools but for different purposes [4], [5]. Both technologies are subsets of mixed reality (MR) that uses various techniques, for instance mobile devices, head mounted displays (HMD), projection and movement tracking systems [3]. VR creates a computer-generated virtual environment that can be interacted with at any time. AR on the other hand takes the real world through a camera of some kind and allows the user to interact with it by placing out virtual objects such as images, objects, and audio in real time. AR is also based on the positioning of the device in some of the applications, allowing for abstraction of large amounts of data as it will only show the data nearby.
The three main characteristics that define Augmented Reality[4] are the following:

- AR combines real and virtual information.
- AR is interactive in real time.

- AR operates and is used in a 3D environment.

Analysis of sources (Table 1) has been conducted to learn the state-of-the arts in Augmented Reality domain.

**Table 1**

Literature review Augmented Reality domain for navigation

| Source | Purpose | Design | Method of Research | Results | Conclusion |
|---|---|---|---|---|---|
| Bernelind, S. (2015)[6]. | An investigative study if AR can be used for improving the navigation | Master Degree Thesis | A Qualitative set of interviews | A large set of data of the parameters described in [6]. | AR is not necessarily when walking compared to Google Maps but when driving it has potential. |
| Larsson, M (2018)[2] | An investigative and comparative study if AR can be used to improve locating city by visualizing data instead of 2D means | Master Degree Thesis | Quantitative and qualitative study, development of AR-based mobile app for Android OS | A study based on the results of the survey | AR could be used to improve finding nearby city services but not in its current state |
| Irshad, S., &Rambli, D.R.A (2014)[7] | An effort to summarize the current research regarding UX of MAR. | A summarizing study | Literature study | A central gap in the literature has been identified on how to design for quality experience of users in MAR. | It is evident from the number of findings that there is a need to address UX related issues like UX evaluation in MAR. |
| Kipper, G. (2013)[4] | A summarization of what AR is, can be used for and the potential for the future | A summarizing study | Literature study | A comprehensive summary of AR. | AR is just starting to break out of its infancy. |
| Lando, E. (2017)[9] | Aid the development and design of AR applications at museum settings | An investigative study | A quantitative/ qualitative set of interviews | Vague quantitative results and positive qualitative results | The qualitative data suggest that in-world space have more aspects that would benefit learning |

As can be seen from Table 1, review of the literature and academic studies in the AR domain gives merely theoretical background. Surveys of the research literature suggest that AR currently greatly increases driver's attention. Research in the AR and VR domain is moving fast and several institutes and companies like Tesla, BMW, Pioneer, and Toyota are working on development in AR navigation. [12]. Therefore it was decided to make a review of practical use of augmented reality for navigation (Table 2).

Table 2 shows that AR is used not only for in-built navigation systems in driverless cars, but also for custom use in the form of mobile applications. The analysis has shown that AR + Android OS are the most frequently used combination for mobile development. Therefore it was decided to use the combination of such technologies as: iOS operating system, Swift programming language and augmented reality library ARKit, since there are not so many currently existing iOS based mobile applications and there is still the necessity of research and development.

**Table 2**
Review of currently known mobile applications using Augmented Reality for user navigation

| Name | Logo | Free or paid | Description |
|---|---|---|---|
| Gatwick Airport [13] | | free | Android and iOS-based mobile application for indoor navigation through Gatwick Airport |
| AR GPS drive/walk navigation [14] | | free | This Android-based application uses smartphone's GPS and camera to implement an augmented reality-powered car navigation system |
| Real LiveMaps AR | | free, in-App purchases | Android-based live maps for navigation. Use in trips or while traveling. Search makes it easy to plan trips and itineraries. |
| Augmented Reality extension for Locus Map [15] | | The addition is in BETA version and works with Locus Map Pro application. In Locus Map Free, its usage is limited to 1 minute. | Additon for Android-based Locus Map application that enables visualization of selected points on the device screen with camera view - in augmented reality. Useful during town sightseeing tours, on viewtowers, for geocaching or for simple guidance to any point. The add-on is in BETA version and works with Locus Map Pro application |

## 3. Augmented reality-based technology for route planning and visualization

As can be seen from Figure 2, AR-based system uses real-time video stream as input data. After processing the video and adding augmented reality elements to build the route that involved the user and environment, the route is being built and saved in the application. This route can be reproduced again once a user needs it or transferred to another user and opened with the same application. Reproducing the ready-built route, that is the output data of the system, also requires user and environment engagement.

To automate the work of the AR-based technology, on which the work of mobile application is based, it is necessary to make the decomposition of the system. The structure of the technology is shown in Figure 3. The work of the technology requires the camera of the smartphone to be enabled.

First, iOS requires the camera authorization from the user, and shows the “Allow” button. Every time when a user opens the application this requirement is shown and needs to be checked by the user. Then, the CoreLocation framework is used to get user location from the iOS system. After that, the recording can be started — camera session starts, camera preview layer is displayed on the screen. User has one option - tap on the “Start” button, then the 3, 2, 1 timer is displayed and the user can start going to any point and record their way. This entire route is recorded using small 3D objects, which are called SCNodes. SCNodes are parts of SceneKit framework [17].

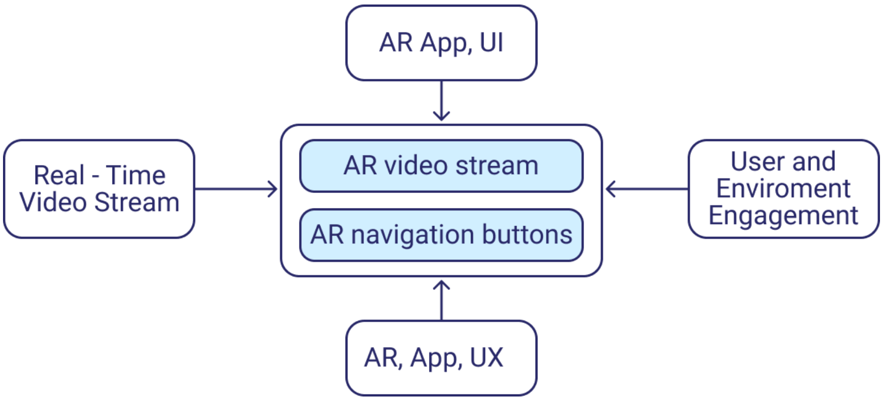


**Figure 2:** Functional block diagram of mobile application for real time routing based on AR-technology

Then all these nodes are connected to one UIBezierPath object. All the information is converted to container NSSecureCoding, which can be saved to device memory. All the routes are available to save and can be reproduced when needed. User can reproduce any needed recorded route from point to point in real time, using AR-based Data on Device location and orientation in Camera View.

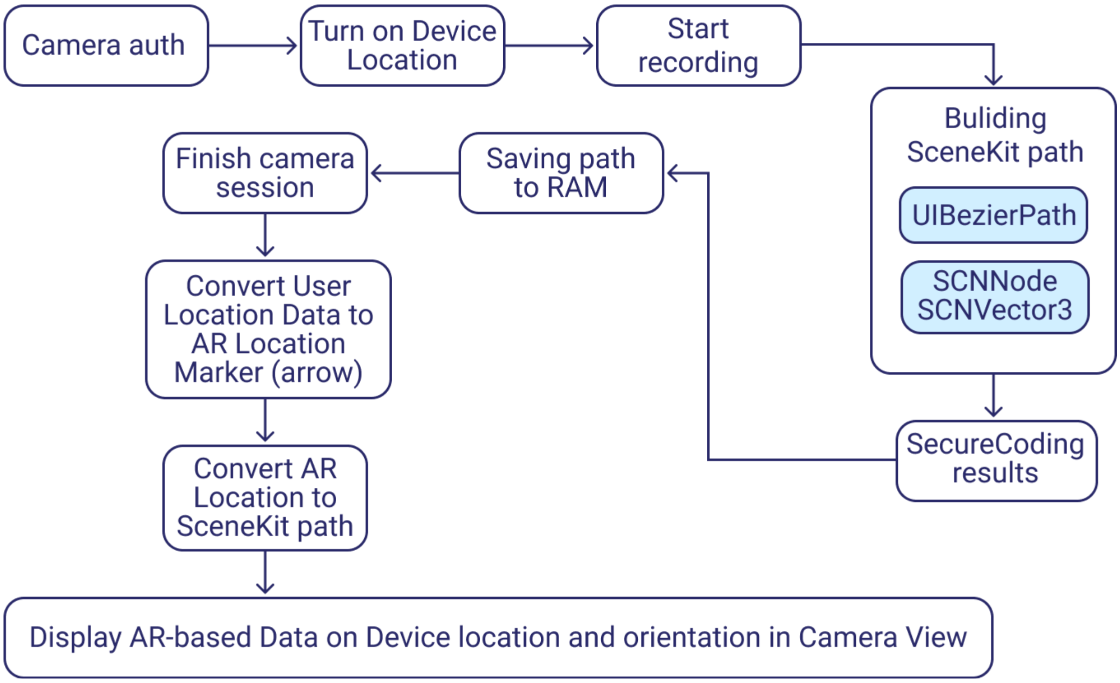


**Figure 3:** Structural diagram of AR-based technology for route planning and visualization

To work with augmented reality technology using the ARKit library, it should be noted that during the experiment (setting a 3D route) the phone will be in three-dimensional space (Figure 4), so it is necessary to consider several aspects. The coordinate system used in ARKit is a right-hand coordinate system. The reduction of the first coordinate of an augmented reality object is to bring together three coordinate systems - the world coordinate system, the object coordinate system and the camera coordinate system in one point [19].

The world coordinate system is determined when the user's device recognizes the outer space to start the session. An object that is placed in augmented reality space is given an absolute position in this coordinate system.

The coordinate system of the object in which the visualization is performed: the object must be placed in the world coordinate system, while having its absolute position.

The coordinate system of the camera must match the coordinate system of the object. After launching ARKit, the user moves the smartphone in space. At this time, the camera changes the coordinates from the world coordinate system and the object is already in the coordinate system of the camera [19].

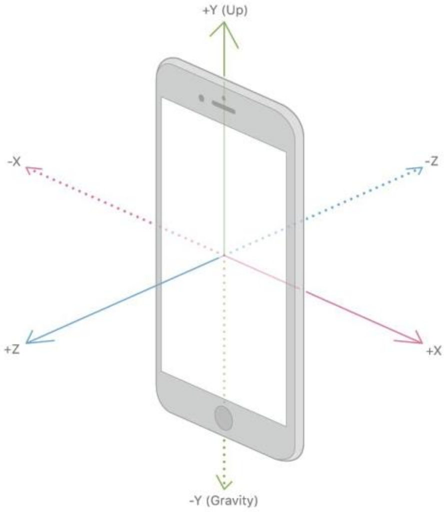


**Figure 4:** Location of the user's phone in three-dimensional coordinate system (in 3D space) [20]

The relationship between the camera's coordinate system and the screen's coordinate system can be expressed using the formula (Figure 5).

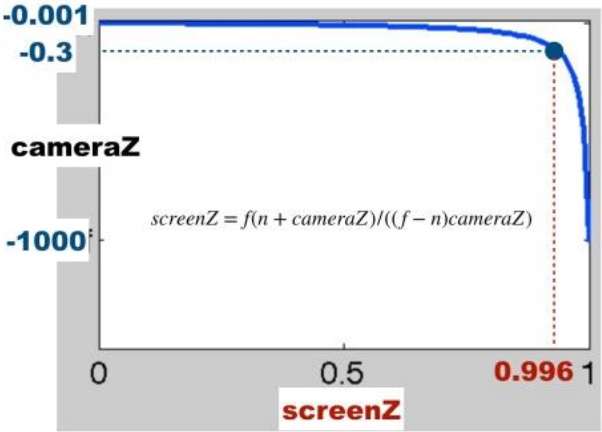


**Figure 5:** Relationship between camera coordinate system and screen coordinate system [20]

Thus, the matrix of the projection of the image on the screen P can be determined by the Formula 1:

$$P = \begin{pmatrix} x & 0 & 0 & 0 \\ 0 & y & 0 & 0 \\ 0 & 0 & (f+n)/(n-f) & 2fn/(n-f) \\ 0 & 0 & -1 & 0 \end{pmatrix} \quad (1)$$

where x and y regulate the angle of view and the ratio of the sides, f and n - the depth of distance and approximation to a certain distance, respectively [17].

Thus the projection of a point in the world coordinate system z = (0 0 z 1) $^T$ is given by calculating p = P * z, and then using the perspective distribution q = p / p.w. Next we need to calculate the depth of the window by the formula winZ = (q.z + 1) / 2.

Following these formulas, we can derive a relationship between winZ and the z coordinate of our point on the z axis. Namely,

winZ = (p.z / p.w + 1) / 2
p.z / p.w = 2 * winZ-1

$$p.w = -z$$
$$p.z = z * (f + n) / (n-f) + 2fn / (n-f)$$
$$(z (f + n) / (n-f) + 2fn / (n-f)) / (- z) = 2winZ-1$$
$$z = fn / (f * winZ-n * winZ-f)$$
$$\text{or equivalent to } winZ = f (n + z) / (f-n) z \qquad (2)$$

It is notable that when z = -f, then winZ = 1, and when z = -n, then winZ = 0. Meanwhile, we have the inverse relationship (Figure 6):

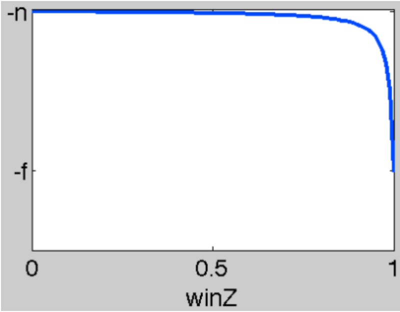


**Figure 6.** Inverse relationship between camera coordinate system and screen coordinate system [20]

During the research, an augmented reality-based information system has been developed in the form of a mobile application for iOS using Swift programming language and ARKit library. This system allows to record the route from point A to point B in real time, save it and display it using augmented reality (the direction of movement from point A to point B is shown by arrows) at the request of the user. All user-recorded routes are stored in the mobile application database and available for sharing for users who have the app installed on their phones.

In the course of the research, an augmented reality-based information system has been developed in the form of a mobile application for iOS using Swift programming language, ARKit library and SceneKit framework. This system allows to record the route from point A to point B in real time, save it and display it, using augmented reality (the direction of movement from point A to point B is shown by arrows) at the request of the user. All user-recorded routes are stored in the mobile application database and available for sharing for users who have the app installed on their phones.

## 3. Experiments

The experiments have been conducted over the campus of Khmelnytskyi National University (KhNU). The following technologies have been used to accomplish the task of the research: iOS operating system, Swift programming language and ARKit augmented reality library. Two of the most popular routes were plotted on the campus plan (Figure 7).

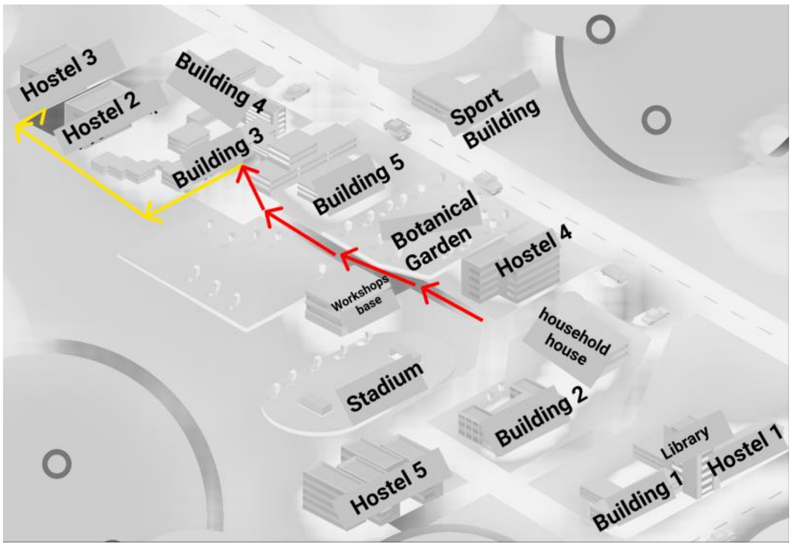


**Figure 7.** KhNU campus plan with marked routes for visualization using augmented reality information technology

The route marked yellow is the route from academic building 3, where the administration of KhNU is located and the classes are held, to Hostel 3, where the students of IT faculty live.

The route marked red is the route from Hostel 4, where foreign students live, through the botanical garden passing the workshors base, where some practical classes on Technical disciplines are being held, towards academic building 3.

Figure 8 shows interface windows of the developed AR-based information system for route planning and visualization.

a) main screen (after the authorization);
b) main menu with the saved routes;
c) the process of routing using augmented reality.

a) b) c)

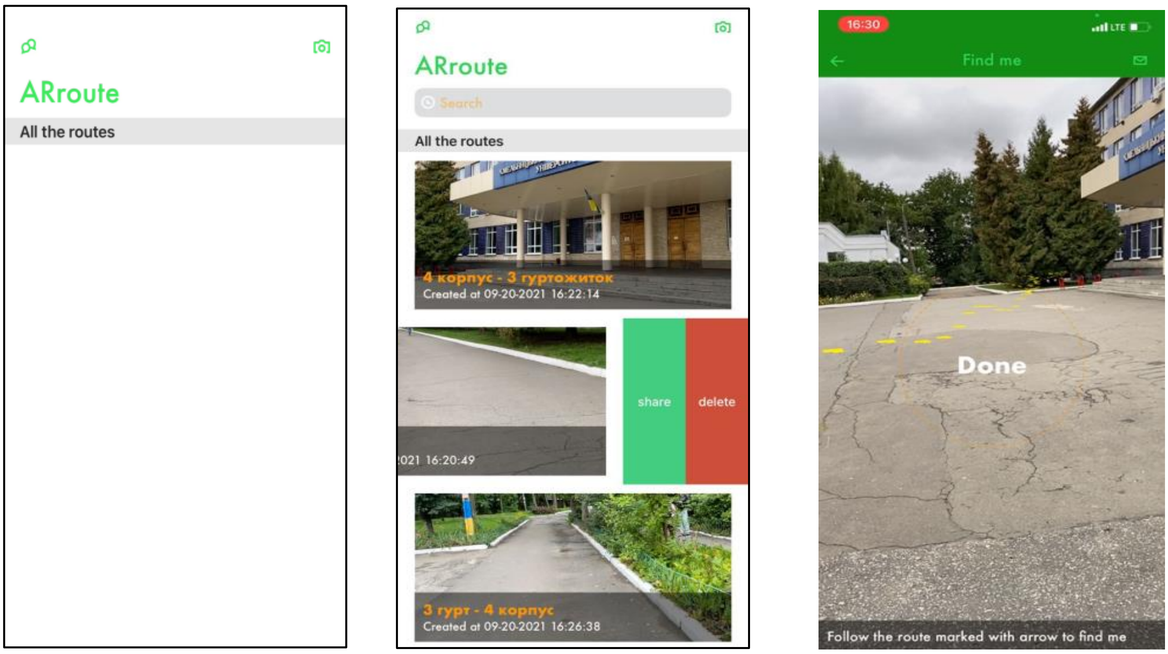


**Figure 8.** Interface windows of AR-based mobile application for routing and visualization the routes.

## 4. Results of performance testing & Discussion

The quality and the efficiency of ARroute application was comparatively evaluated using the main performance parameters, such as Memory usage, Application Launch Performance, Memory Leaks, maximum CPU usage, Energy Impact and quantity of frames per second (FPS). Proposed architecture and software development model in this paper works quite well as compared to the other similar applications. The comparative analysis has been conducted between ARroute and Feed Me application [21], which uses Google Maps iOS SDK i.e. literally can be perceived as Google Maps itself. The launch has been performed on iPhone 11 with iOS 14.7.1. Also proposed in this paper ARroute application is more user friendly as compared to similar systems, in our case Feed Me, as it has an intuitively built interface and understandable principle of use.

Figure 9 shows that panorama views and 3D routing provided by Google Maps use already taken and saved by other user videos. For the experiment we tested 3D route across Botanical Garden. The time stamp shows that this video has been taken in April 2019. Therefore we can conclude that Google Maps do not provide real time 3D routes paving. In return ARroute provides real time route paving. It helps user to intuitively build the route using augmented reality markers. The saved route can be reproduced using a device camera in real time once needed.

**Figure 9.** 3D route across KhNU Botanical Garden used Google Maps application

Table 3 shows the comparative analysis of ARroute application and Feed Me (Google Maps) in the main performance characteristics.

**Table 3**
Results of performance testing of ARroute and Feed Me(Google Maps) application using Xcode tool.

| Characteristic | Feed Me application (Google Maps) | ARroute application |
|---|---|---|
| Memory usage | 137 MB per 188 seconds | 185 MB per 189 seconds |
| Application Launch Performance | 16.44 seconds | 3.76 seconds |
| Memory Leaks | No leaks | No leaks |
| Maximum CPU usage | 67% | 85% |
| Energy Consumption | High | Low |
| Frames Per Second (FPS) | 49 | 57 |

Memory usage is mentioned as one of indicators for efficiency and correctness. So we use this parameter as an efficiency indicator in comparison with other projects. To calculate memory usage, the compared applications have been run with a time duration of approximately 3 minutes and have been actively used. The given experiment data take the average value of each category.

Application launch performance time indicates how much time it takes for application to run. The results of the experiment showed that ARroute needs less time to launch.

Memory leaks happen when no longer needed objects in memory that can not be released for various reasons and can lead to memory loss, poor performance and due to closing, departure or automatic application crash. According to the experiment, in both applications there are no problems with memory leak.

In return ARroute has higher level of CPU usage at peak times.

Energy Impact shows how much battery power the device consumes to perform tasks. This rate is very high in Feed Me and low in ARRoute.

Frame rate (FPS) is the frequency (speed) at which the image processing device displays consecutive images called frames. This indicator shows how quickly, smoothly and clearly the graphics of the application is displayed on the smartphone screen. In spite of using augmented reality technology, ARroute has a higher FPS indicator than Feed Me (Google Maps), which only uses the user's location.

## 5. Conclusions

Thus, the proposed augmented reality-based information system for routing and route visualization provides quick and accurate route paving and saving the route with the following display at the request of the user.

During the study the survey among students was conducted, which showed the relevance and the necessity of the research and development of the proposed mobile application. Also the literature analysis and analysis of already existing AR-based mobile applications provided the conclusions about the technologies that have been used for the development of the proposed augmented reality-based information system for routing and route visualization.

The performance testing, which has been performed during the experiment, showed that the proposed ARroute application has high application launch performance, no memory leaks, low energy consumption and high image processing frequency.The developed application works quite well, has a user friendly and intuitive interface.

The further efforts of the authors will be directed to improving the existing algorithms for the work with augmented reality technology, conducting more experiments and improving the proposed mobile application.

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