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Towards an Augmented Reality Application to Support Civil Defense in Visualizing the Susceptibility of Flooding Risk in Brazilian Urban Areas

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Abstract. This paper presents an augmented reality application for visualizing floods in urban environments, aiming to raise awareness people about occupied areas susceptible to flooding, based on historical occurrences. Environmental disasters by flooding have occurred frequently in different regions of Brazil, where urban areas grow fast with low Master Plan control and integrated use of flood risk maps. At the same time, Civil Defense have been challenged on strategies of how to convince the population to abandon their homes in an iminent flood disaster. In order to help and support these strategies, mainly to avoid occupations in susceptible areas that may be irregular or not, it was developed a mobile application named "Neocartografia". The main goal of the application is to show ordinary people the potential effect of flooding presented in real time and interacting with their own buildings. The idea of integrating the real image of the environment with the simulation of a certain depth of flooding, being set manually or related with hydrological and hydraulic modelling. The Civil Defense agents point the smartphone to the citizen's home, through augmented reality and simulates in the real world the depth of the water according to some parameters (speed, depth and extent of the flood waves). The results earned with the first version of Neocartografia Application have been sufficiently good to reach the developers first goals, but still must be improved.

Supported by organization CNPq through: a) project 426911/2018-0 by the call MCTIC/CNPq Nº 28/2018 - Universal; b) project 307153/2019-3 by the call CNPq Nº 06/2019 - Bolsa de Produtividade e Pesquisa. Special thanks to FAPESC by support the research through the call FAPESC Nº 27/2020 - FAPESC/TO - 2021TR857, and also to Santa Catarina Civil Defense for the partnership. This research received financial support from the Coordination of Superior Level Staff Improvement - CAPES - Brazil (PROAP/AUXPE).

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O. Gervasi et al. (Eds.): ICCSA 2022 Workshops, LNCS 13378, pp. 494–506, 2022.
https://doi.org/10.1007/978-3-031-10562-3_35

Keywords: Flooding visualization · Augmented reality · Augmented reality geovisualization · Flood awareness

1 Introduction

Brazil is characterized by being a country that has a territorial extension of continental size and therefore several and different planning actions in its 5.570 municipalities. Among the forms of territorial occupation associated with the land use policies, there are regions with specific profiles, which present specific constructive characteristics in buildings and which are distinctly related to land uses and occupation. The national territorial extension of the Brazilian coastline is approximately 7.491 mi. In addition to the Brazilian hydrography characteristics, it occupies a prominent place among the natural elements.

Despite its national hydrographic wealth, Brazil has historically shown, since its discovery, a significant importance in the formation of urban centers in coastal regions or in inland cities where the banks of rivers have become natural attractions and a basic parameter for the formation of the urban nucleus.

Santa Catarina was a state in southern Brazil that suffered an intense process of rural exodus and therefore many urban centers were impacted by occupation and increase of population density. In this scenario, new buildings appeared in areas not recommended by the master plan, or by occupation actions in irregular areas. As a side effect, the ability of a city (or locality) to become resilient to natural flood events has gradually received more attention from managers/planners, as well as technological advances. Even aware of the susceptibility and vulnerability to which the citizen is exposed, as well as the urgent demand for risk reduction, genuine mitigation actions often only occur after the occurrence of flood events and their respective harmful effects [15].

Therefore, knowing, respecting and especially understanding the meteorological and hydrodynamic condition associated with the risk of flooding or floodable areas around rivers (especially in urban areas) and ocean coast is essential to exercise the resilience of cities and urban centers, as well as to define adequate urban parameters and restrictions on occupation. The concept of population resilience in the context of flood risk management relates to when the urban water system faces floods [15]: (a) the ability to withstand flood events, or the ability to protect against floods; (b) resilience when events occur, or the ability to minimize damage and support a fast recovery; and (c) the self-organization, learning, and adaptability of the system.

The impacts of floods are recognized by the scientific community as being of a complex nature and therefore need to be properly identified and monitored [14]. Whatever the severity of a flood, the impacts to those who are affected can be complex and intangible. Tangible flood impacts are those that are easy to estimate in monetary terms, such as the cost of reintegration or replacement cost of damaged items [13]. While intangible impacts are those that cannot be immediately evaluated, they are often described in qualitative or quantitative terms, such as loss of irreplaceable items or items of sentimental value, health impacts, and psychological effects of flooding.

Residential resilience can be understood as the ability of a property/building to recover from the effects of floods without causing serious damage to the property/building structure [6]. Therefore, to achieve resilience to floods in homes [12], different procedures can be taken: for example, raising items such as electrical outlets above the expected flood levels; or using resilient materials that do not deform/disintegrate on contact with water, such as cementitious materials. In all cases, it is important to ensure that water can be expelled from the building quickly and that an adequate air circulation is maintained around the exposed elements for a reasonably quick drying. For any building, therefore, there may be several possible strategic solutions to contain the ingress of water [12].

On the other hand, it is also important to consider and act in the development of technologies that help citizens to recognize the susceptibility associated with the location of their property, making public and disseminating technology applied to the recognition of potential areas subject to flooding is fundamental, since the climate change is increasingly showing the recurrence of disastrous and intense effects in urban centers related to flooding. In this context, Brazil is still at an embryonic stage in technological development and therefore needs to exercise the power of mitigation or scalable solution of the climatic events effects of intense and concentrated rains that cause floods in urban areas.

Aware of the Brazilian reality and especially the susceptibility of Santa Catarina cities to the harmful effects of floods and the need of the Santa Catarina Civil Defense to act with technological resources accessible to the citizen, aiming to recognize the vulnerability of their housing, the "Neocartografia" application was developed. This application has the purpose of identifying the building and by computational processing using Augmented Reality resources, to project potential different levels of flooding on the image that represents the building.

2 Related Work

At the beginning of the research, the idea was to develop an application that would be useful to society and that would also support actions to raise awareness of society for the Santa Catarina Civil Defense in urban occupations of areas that are susceptible to flooding. In this way, as a starting point for the development of the application, a bibliographic survey was carried out to support the technical, scientific and technological development of the application, taking as a reference other products, prototypes or similar applications - therefore, based on other ideas, the Neocartografia application proposal was conceived and built by the team of researchers. The initial aim was to carry out a scientific exploration of applications for smartphones that could combine scientific and technological concepts related to the interface between cartography and augmented reality.

Based on this principle, the study developed "Innovative Applications of VR: Flash-flood control and monitoring" presents a technical solution that combines virtual reality with augmented reality [8], aiming at the control and monitoring of flash floods.

Another study considered as a reference in the Neocartografia application development research was the one entitled "An efficient flood dynamic visualization approach based on 3D printing and augmented reality" [16], which presents a technical-scientific and technological proposal that combines the reality increased with the creation of a 3D world at different scales, aiming to simulate the occurrence of floods.

Another application entitled "Disaster Scope" [5] was identified in the scientific databases. This application has similar characteristics to the Neocartografia, and its main purpose is to make citizens aware of local susceptibilities and risks related to flooding processes. It was developed in Japan based on the earthquakes that occurred in 2011, as well as the heavy rains of 2018. These natural events hit the population and caused severe consequences, suffering and loss, since people were aware of the size of the risk they were facing and the degree of susceptibility involved.

The"Disaster Scope" application provides local flood simulation, as well as the Neocartografia application, where the augmented reality visualization is calculated in real time and can have its parameters changed in real time. However, the "Disaster Scope" flood simulation requires the use of virtual reality glasses so that the user can immerse himself in the scenario even more.

Another relevant scientific research that was highlighted in the databases, whose projected parameters are similar to those developed in the Neocartografia project, was verified in the Mobile Augmented Reality for Flood Visualization [2] project. The research presents a differentiated application, since the device, instead of performing the detection of plans automatically, demands from the users to touch the screen in order to create anchor points that later will be used for occlusion on the flood simulation.

The studies developed in [11] considering "3D Virtual Environment for Storm Surge Flooding Animation" were focused on the 3D representation of the virtual world where floods occur. Based on the same concept, it appears that the company Bentley Systems also develops similar software solutions and presents"OpenFlows" to the market. Thus, Bentley software produced a digital twin model of the city's water supply, wastewater, stormwater, and bathing water systems, to forecast flooding and water quality issues, thereby improving city response and resilience. But especially the FLOOD software from Bentley allows modeling and the simulation of extreme events using accurate and reliable flood risk analysis data. FLOOD is a flood modeling software for analyzing and mitigating flood risk in urban, riverine, and coastal areas. Using spatially distributed numerical models, users can quickly simulate all hydrological and hydraulic processes to support emergency planning and green-initiative design. Apply a multi-scale 1D/2D approach to support flood early warning systems (FEWS).

It is also important to consider the promising scientific work presented by [3] entitled "In-situ Flood Visualization Using Mobile AR", which uses a computed method of interactive triangulation by correspondences of natural and augmented point.

Finally, it is possible to assume that Virtual Reality (VR) and Augmented Reality (AR) are new techniques for flood visualization that could provide a stereoscopic 3D visualization environment and a user-friendly interactive interface through natural body posture. In fact, VR flood visualizations are more intuitive and realistic than are screen-based 3D visualizations and involve more natural human-computer interactions [1,7,9]. However, VR creates a totally immersive virtual environment isolating users from the real-world circumstances, which also impedes interactions with other users. AR flood visualization superimposes virtual flood scenes over the real environment; therefore, virtual floods and real environments could be observed synchronously, which could address the issue that exists in current VR flood visualizations.

3 Floods in Santa Catarina and Civil Defense

Between 1980 and 2010, there were 1.344 episodes of gradual flooding in Santa Catarina, which left thousands of people homeless and caused serious socioeconomic impacts in the municipalities that were affected. It is noteworthy that the gradual floods correspond to 19,6% of the total natural disasters that devastated the State in the period between 1980 and 2010 [4]. In the months of May and July of 1983 and August of 1984, Santa Catarina faced the most catastrophic floods of the 20th century, which mainly affected the Itajaí Valley mesoregion. During the floods of July 1983 in the State, 197.770 homeless and 49 deaths were recorded, and the most damaged cities were located in the Itajaí-Açu River basin, highlighting the city of Blumenau with 50.000 homeless and 8 dead, which represented 29.3% of the total population of the municipality [4,10].

The year of 2008 was also defined as exceptional, due to the rainfall that occurred during the months of September to November, and were continuous, from moderate to strong intensity, and between the 21st and 23rd of November 2008, from moderate to strong intensity, in a constant way, causing a fast rise in the level of rivers with overflow and rapidly expanding the flooded areas. In fact, the disasters occurred in different cities between the 21st and the 25th of November, whose records of concentrated rainfall during those 5 d were greater than 550 mm.

The graph on Fig. 1, the importance of developing the "Neocartografia" application is concretely justified, since the repeatability of the occurrence of the flood phenomenon recorded by the official state agency (Civil Defense) associated with the harmful effect of the event (flood) that was reported between the years 2013 to 2021. The harmful effect of floods on the state's economy is significant and undoubtedly much more marked in people's lives.

As a clear example of the occurrence of floods, Figs. 2 and 3 present two affected urban areas, the first representing affected low-income buildings and the second a more economically wealthy place. The two examples demonstrate that in the urban planning of Brazilian cities, there is a lack of care when occupying places susceptible to the event of flooding and the lack of control of the public authorities to stop constructive advances - since the real estate market has great power.

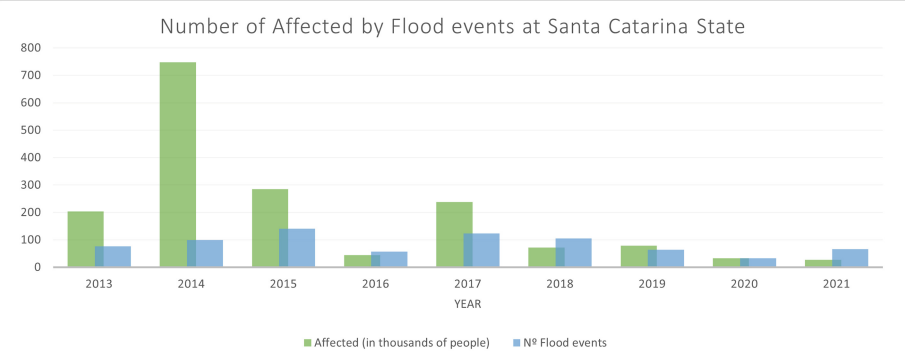


Fig. 1. Graph shows the relation between floods in Santa Catarina State and people affected by it.



Fig. 2. Frequent example of an urban area flooded after a heavy and fast rain. Source: Town hall of São Bento do Sul city/Santa Catarina (2021)



Fig. 3. Effects of flash flood on wealthy building underground garage at Florianópolis city. Source: the authors (2020)

The developed device will allow the user to download the application and, having available the historical data of the occurrence of floods in the place, will automatically have available on the screen of his smartphone the projection of the water feature (virtual) applied to the real image - facade of the building.

The visual impression will help the user to decide to stay in the place of potential risk, recognize and identify the dynamics of the phenomenon and the impact on buildings and movable assets.

The Civil Defense will have one more instrument to support management and raise awareness of citizens which, through the visualization device of the "Neocartografia", will place themselves in a new environment of interaction and spatial representation of the object and phenomenon.

For people who experience the problem and suffer the effects of flood events, in their respective recurrences, they somehow learned to be resilient and Figs. 4 and 5 show it in fact. In the first situation (Fig. 4) it is verified that the owner raised the level of the public sidewalk and also the internal area of the patio of his property. In Fig. 5 - from the opposite point of view, that is, from inside the house to the outside view, it is possible to see the lowered level of the kitchen. With this behavior, the resident of the property created a barrier and a potential damming if the flood is higher than the concreted area.

The history of flood occurrences and the projections by "Neocartografia" application will help the owner to make decisions about which technical actions are effective to mitigate the effects of the flood, or improve resilience techniques.



Fig. 4. Main entrance to the house with a concrete elevation on the sidewalk to avoid the damaging effects of flooding. Source: authors (2019)



Fig. 5. House with backyard elevation that causes a barrier and the kitchen at same street level, resilience that needs to be improved. Source: authors (2019)

Currently, the Santa Catarina Civil Defense has a weather forecasting system as technology, which, when identifying a potential flood event, automatically sends an alert SMS (Short Message Service) to residents (registered on the alert platform).

Therefore, the Neocartografia application is configured as another instrument to help prior to the occurrence of the flooding phenomenon that will instruct the users about the susceptibility to the problem, since occupying these places in which their houses are located, they are subjected to the harmful effects of its occurrence.

4 Neocartografia: An AR Application to Simulate Flood Events

The main goal of the Neocartografia application is to be used as a tool to demonstrate real-world flood events in an augmented reality situation. It can be used by civil defense agents to predict the water depth situation in the residents' homes, and then convince them to withdraw and secure their lives.

This software was developed using the Unity game engine, which has several libraries and documentation about augmented reality applications that facilitate the development process of this solution. The first version of Neocartografia was made using the ARCore framework. It's a development platform for creating augmented reality applications developed by Google. It had the limitation of only being able to create android AR applications. However, ARKit is a set of tools created by Apple to aid developers in creating augmented reality applications for iOS devices. ARKit had a similar limitation as ARcore, it only allowed to create IOS applications. Finally, AR Foundation is a package that allows building cross-platform AR applications in Unity. AR Foundation can use features from both ARCore and ARKit frameworks in the same project. So, it works with horizontal and vertical plane detections on Android devices. Then we decided to migrate from ARCore to the AR Foundation framework.

It's well known and established that iOS devices can run augmented reality softwares better in major categories. Devices like iPad Pro 2021 and iPhone 13 Pro have a LiDAR scanner next to the camera that increases the overall potential of identified areas in augmented reality. Most Android devices can run AR applications up to 30 Frames Per Second (FPS) where iOS devices can run up to 60 FPS, giving a more fast and fluid simulation. There are some Android devices like most Pixel phones and the Xiaomi MI 11 Ultra that support the same as iPhone. The choice was obvious to develop Neocartografia for iOS devices. However, the sale prices of Apple devices in Brazil make it infeasible to purchase them. Consequently, we focus development and testing on Android devices.

AR Foundation uses a point cloud manager that creates sets of feature points. A feature point is a specific point in the point cloud which the device uses to determine its location in the world. The plane detection is done from a point cloud. Figure 6 illustrates the algorithm of real-time extraction of planes developed in Neocartografia. First, it identifies the planes and assigns an anchor to some specific points. Then, it identifies the lowest point on the Y axis, this will be the main anchor until a lower anchor is identified. So this main anchor is used to generate the water plane in the X axis and place it in a Y axis + Depth (informed by the user). This plane has all the water attributes to make a more real simulation, such as wave size and speed, and it uses a mesh renderer with water texture. The waves simulation is made by displacing parts of the mesh, giving to the texturized plane a water-like movement. AR Foundation gives an extra layer of immersion with an occlusion script that interacts directly with the water plane, merging real life objects with the simulation. This feature is illustrated in Fig. 7 where the water plane is occluded by the walls.

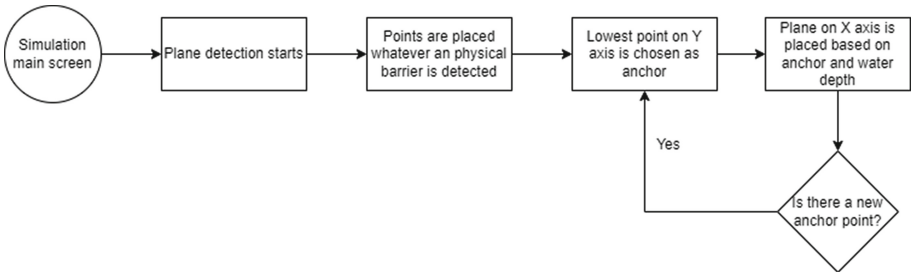


Fig. 6. A macro view of Neocartografia's system using a flowchart.

Neocartografia's interface was designed to make interaction with the application simple, without major compromises. The user simply points his or her smartphone in some direction, and the planes are detected. Then she/he can adjust the simulation parameters: water depth, waves speed and size. Figure 7 demonstrates this interface.

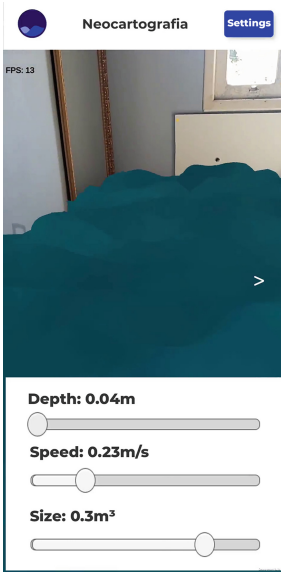


Fig. 7. Neocartografia simulation screen with settings menu open.

The National Water and Sanitation Agency (ANA) collects all kinds of data about rivers and lakes and uses it to ensure sustainable use of these river resources. It provides a free API to query a specific water station on a series of dates. The use of the API and some of the results are exemplified in Fig. 8.

```
http://telemetriaws1.ana.gov.br/ServiceANA.asmx/DadosHidrometeorologicos?CodEstacao=83800002&DataInicio=07/08/2021&DataFim=08/08/2021
<DadosHidrometereologicos diffgr:id="DadosHidrometereologicos1" msdata:rowOrder="0">
    <CodEstacao>83800002</CodEstacao>
    <DataHora>2021-08-08 23:45:00 </DataHora>
    <Vazao>9.97</Vazao>
    <Nivel>25.00</Nivel>
    <Chuva>0.00</Chuva>
</DadosHidrometereologicos>
```

Fig. 8. Example of communication with ANA's API.

In order to give an opportunity to investigate data from historic flood events, Neocartografia allows simulates flood events, for instance, that happened ten years ago. This feature enables civil defense agents to get information about areas that are at risk from a similar event.

Figure 9 demonstrates on (A) how this integration works in Neocartografia. In the search screen, the user fills the station ID and the time period. Figure 9 (B) shows the search result. There is a combobox component with the series of measurements identified by the date and time stamp. User selects an item from the combobox and clicks on it to reveal what was the flood situation on that specified date and time.

Based on our tests and with the limitations in mind we came up with a formula of how to improve floor identification; Fig. 10 represents on (A) the main formula, where the effective view and effective simulation distance lean on the angle of A and total height of Y, simplified by the function:

$$E = |(A/180)| - Y \tag{1}$$

Where E =<0 better

Still considering the same figure, example B shows the simple scheme where by the formula, the effective view and effective simulation distance lean on the function:

$$E = |Y| - |A| \tag{2}$$

Where E =<0 better

The two formulas presented above aim to obtain a more precise identification of the X plane and an ideal height of the device for this purpose is between 1 and 8 m.

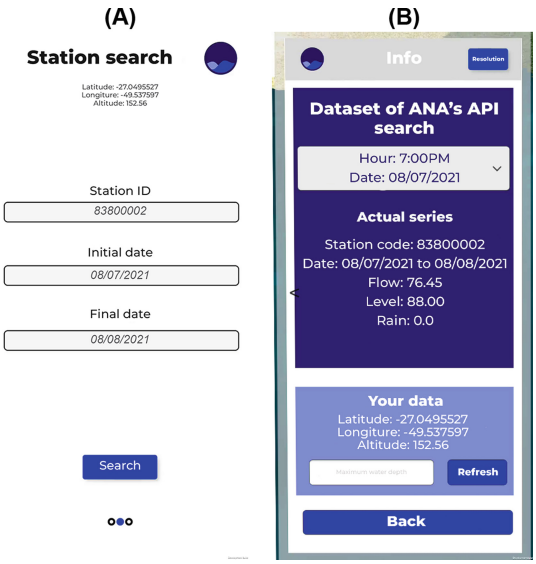


Fig. 9. ANA API screens on Neocartografia being: A) Search screen of ANA historic event; B) Result screen.

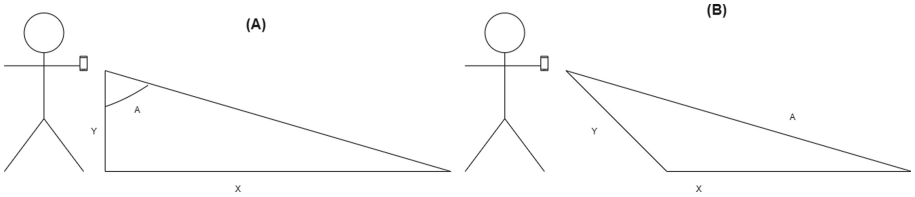


Fig. 10. User and device triangulation on (A) and device view triangulation on (B).

5 Discussion and Conclusions

The general perspective of AR flood visualization involves superimposing the scaled virtual flood scenario onto the real environment (urban), which could provide a better visual perspective for flood mitigation or decision making.

As described in the Related Work section, significant efforts are being made to simulate flooding and visualize it in real urban environments. The present work presents a low-cost solution that can be affordable for the population. Although the focus of the development is on an application to support Civil Defense, the direction of this work is focused on moving forward so that any citizen can perform the simulations at home.

The tests performed by the Neocartografia application developer team showed that the device is useful and has a valuable application for the reality of irregular occupations in urban centers of Brazilian cities, presenting an excellent performance as a system for visualizing the susceptibility to risk in which families are exposed. The visualization of AR projected on the buildings brings a real approximation regarding the risk and danger to which the residents are susceptible, reducing the need for technical arguments about moving from that place.

The application also proved to be important for integrating databases, such as the National Water Agency (ANA), which keeps historical data on the processes and harmful effects of urban floods, as well as other technical parameters.

Finally, the system described on the present study indicates the assessment of 3D hydrodynamic simulation of flooding, allowing to assist the state, through control and monitoring, by showing people what a expected amount of rain is capable to reach in terms of flooded areas instantaneously visualized, based in the specific topography established. In conclusion, the Neocartografia is an application useful for assisting participants, civil defense and decision makers in understanding the flood hazard at different urban areas and also provide a more intuitive and realistic visual experience, based on AR technology.

From the observed results, it can be concluded that the Neocartografia application reached its purpose considering the first version developed. Furthermore, similar technologies related to this research must be supported by national agencies and developed by experts from academia to mitigate the effects from natural disasters in Brazil.

6 Challenges and Recommendations for Future Work

Therefore, still some issues need to be solved. First, hardware limitations restricted some test cases. Besides not being able to use iOS devices with LiDAR technology, we noticed that in a wide outdoor environment, the camera in our smartphones (Samsung Galaxy Note and S 2018 series) could not correctly identify distant planes, thus not placing the water plane in places not close to the device's camera.

Test suites in partnership with the experts that work at Santa Catarina Civil Defense will be the next steps, from which we can improve the application features.

For future work we intend to make the Neocartografia searches on ANA's API even better to query and visualize on the application. An IOS version could carry out the actual potential of simulation to a higher level and also adopt the smoothness of data input using the LIDAR technology, which would make the distance measurements more trustful for collecting data and also for visualization.

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